Combustion Engineering Technology
Cross Training Course Manual

Chapter 5

CHEMICAL AND VOLUME CONTROL SYSTEM

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5.0 CHEMICAL AND VOLUME CONTROL SYSTEM

Learning Objectives:

1. List the purposes of the chemical and volume control system (CVCS).

2. List in flow path order and state the purpose of the following major components of the CVCS:

   a. Regenerative heat exchanger
   b. Letdown flow control valves
   c. Letdown heat exchanger
   d. Letdown back pressure regulator
   e. Letdown filter
   f. Ion exchangers
   g. Volume control tank (VCT)
   h. Charging pump

3. Identify the components in the CVCS that are used to purify the reactor coolant and the types of contaminants each is designed to remove.

4. Describe how the makeup system is used to borate, dilute, and makeup a blended flow of boric acid to the reactor coolant system (RCS).

5. Explain why and for what plant conditions the following chemicals are added to the RCS:

   a. Lithium hydroxide
   b. Hydrogen
   c. Hydrazine

6. Describe the emergency boration flowpath, and identify the plant conditions which would require its use.

7. List the plant operations that result in large amounts of in fluent into the boron management system.

8. Identify the changes in the CVCS that occur upon the receipt of an engineered safety features signal (ESF).

9. Explain how the CVCS is designed to prevent the following:

   a. Flashing and pressure transients in the regenerative and letdown heat exchangers.
   b. High temperature in the letdown ion exchangers

10. List the automatic actions initiated by VCT level instrumentation.

5.1 Introduction

The CVCS performs the following functions:

1. Purification of the RCS,

2. Control of RCS boron concentration,

3. Control of RCS volume (pressurizer level),

4. The addition of corrosion inhibiting chemicals to the RCS,

5. Collection of RCP controlled bleed off,

6. Adds boron to the RCS in the event of an accident,

7. Supplies pressurizer auxiliary spray,

8. Provides continuous on-line measurement of RCS boron concentration and RCS activity and

9. Provides a means of testing the high pressure safety injection (HPSI) check valves.

The CVCS is a major system which is in service during most modes of operation. The CVCS (Figure 5-1) starts at the suction of 12A reactor coolant pump (RCP) where coolant is letdown at a flow rate (29 to 128 gpm) dependent upon pressurizer level. The coolant is cooled and depressurized and routed through the purification components. Then the coolant is collected in the VCT. From the VCT, the coolant is pumped back into the RCS by the three (3) 44 gpm capacity charging pumps.

5.2 Letdown (Figure 5-2)

In order to accomplish the functions of RCS purification, pressurizer level control, and the control of boron concentration, coolant must be letdown from the RCS. Purification is accomplished by passing the letdown stream through ion exchangers that require low temperature for proper operation; therefore, heat exchangers are installed in the letdown line to reduce the letdown water's temperature. These basic requirements form the design basis for many of the components in the letdown. In the following sections, the letdown subsection will be discussed.

5.2.1 Letdown Isolation Valves

The letdown subsystem starts with a connection located on the suction of a RCP and is routed to the regenerative heat exchanger. Two (2) series air operated valves are installed in this line and provide manual or automatic isolation of the letdown line.

The first of these valves, the letdown stop valve (CV-515), is automatically closed by high regenerative outlet temperature (470°F) or ESF signals. A high regenerative heat exchanger outlet temperature would be caused by a loss of charging flow. Interlocking the letdown isolation valve insures that cooling water is available to the heat exchanger prior to admitting hot letdown. The letdown stop valve is also closed by a safety injection actuation signal (SIAS). The purpose of this interlock is two fold. First, letdown does not perform any safety related functions and all non-safety related penetrations are isolated during accidents. Secondly, isolation of letdown prevents loss of additional inventory during an accident. In addition, a chemical and volume control isolation signal (CVCIS) will also close the letdown stop valve. The CVCIS signal functions to isolate the letdown line in the event of a letdown line rupture.

The second series isolation valve (CV-516) is called the letdown containment isolation valve. A SIAS close signal is sent to this valve to provide redundancy in the isolation of letdown. A CVCIS signal also closes the letdown containment isolation valve. Both of the two (2) series valves may be manually operated from the control room. Letdown fluid normally passes through these valves to the regenerative heat exchanger.

5.2.2 Regenerative Heat Exchanger

The regenerative heat exchanger is an inverted U-tube heat exchanger with letdown flowing through the tubes and charging flowing through the shell. By cooling the letdown stream with the returning charging flow, a portion of the temperature loss is regained (the temperature is regenerated).

Cooling letdown provides a part of the temperature reduction that is necessary for proper ion exchange operation, and heating of the charging flow minimizes thermal shock to the RCS and pressurizer penetrations.

Under balanced letdown and charging flows, the letdown enters the heat exchanger at 544.5°F and exits at about 263°F, while charging enters at ~120°F and leaves at 395°F. These temperatures will change as letdown and charging flow rates change. Regenerative heat exchanger outlet temperatures are monitored in the control room. As previously discussed, regenerative heat exchanger letdown temperature provides an interlock to the letdown stop valve. The letdown outlet of the regenerative heat exchanger travels from the containment building to the auxiliary building.

5.2.3 Excess Flow Check Valve

An excess flow check valve is located downstream of the regenerative heat exchanger and is installed to minimize the consequences of a CVCS letdown line rupture. The valve is a two (2) inch, alloy 316 stainless steel, spring loaded check valve that is designed to operate at 2500 psia and 650°F. The valve will isolate the letdown line if letdown flow exceeds 210 gpm.

After the excess flow check valve, the letdown line passes through the containment penetration. The containment penetration is cooled by a small heat exchanger to prevent the concrete surrounding the penetration from becoming too hot.

The pressures in the piping penetration room and the letdown heat exchanger room are monitored so that if a letdown line rupture occurred in either room, a CVCIS signal would be generated to shut the letdown stop valve and the letdown containment isolation valve. There are two (2) pressure detectors in each room. If any two (2) of the four (4) detectors sense a room pressure of one-half (1/2) psig, the CVCIS signal will be generated. After passing through the containment letdown isolation valve, letdown travels to the letdown flow control valves.

5.2.4 Letdown Flow Control

The quantity of letdown flow is determined by the position of the letdown flow control valves (CV-110P and CV-110Q) which are modulated by a pressurizer level error. Normally, only one of these valves is in service with the other valve in standby. A selector switch in the control room is used to place either or both valves in service. The selected valve(s) receives the pressurizer level error signal.

During normal operations with a steady pressurizer level, letdown flow is 40 gpm. This 40 gpm combined with a total RCP controlled bleed off (CBO) flow of four (4) gpm matches the 44 gpm capacity of one charging pump. If letdown plus CBO equals charging, pressurizer level should remain constant. However, if pressurizer level starts to drop, then the letdown flow control valve will close to reduce letdown flow. The minimum value of letdown flow is 29 gpm to insure preheating of the charging stream. Conversely, if pressurizer level increases above setpoint, the letdown flow control valve(s) will open to reduce pressurizer level. As the valve opens, letdown flow increases. The maximum value of letdown flow is 128 gpm. This prevents total outflow from the RCS from exceeding the maximum amount of charging. The maximum value of charging, with all three charging pumps running, is 132 gpm. A letdown flow of 128 gpm combined with four (4) gpm RCP CBO equals the charging flow from three (3) pumps.

Both of the letdown flow control valves should never be placed in service when RCS pressure is above 1500 psia because the excessive letdown flow will cause thermal shock to the CVCS.

The pressure drop across the letdown flow control valve is 1630 psi at normal letdown flow. From the letdown flow control valves, flow is directed to the letdown heat exchanger.

The intermediate letdown relief valve is installed in this section of piping to prevent overpressurization of the letdown line and letdown heat exchanger. The valve has a setting of 600 psig (50 psig below piping design pressure) and relieves to the waste processing system.

5.2.5 Letdown Heat Exchanger

The letdown heat exchanger provides the final temperature reduction of the reactor coolant prior to its entry into the ion exchangers. Letdown enters the tubes of this heat exchanger at about 263°F and exits the heat exchanger at about 120°F.

The letdown flow passes through the tube side of the letdown heat exchanger, and component cooling water (CCW) passes through the shell. The shell side of the heat exchanger has baffles installed to direct the flow of CCW in a counter flow direction across the tubes.

Letdown heat exchanger outlet temperature is used to automatically control the flow of CCW. If letdown temperature goes above setpoint, CCW flow is increased by opening the letdown temperature control valve (CV-223) located in the CCW outlet line. Of course, if temperature decreases, CV-223 will close down.

In addition to controlling the CCW flow through the letdown heat exchanger, letdown temperature is used to isolate flow through the boronometer and radiation element, and to bypass flow around the ion exchangers.

5.2.6 Letdown Back pressure Regulators

After letdown temperature has been reduced, its pressure can be reduced. If a pressure reduction was attempted before the water was cooled, then the letdown would flash to steam. In order to prevent flashing, letdown back pressure regulating valves are installed to maintain a pressure of 460 psig on the letdown heat exchanger and upstream piping. 460 psig is greater than the 422 psig saturation pressure that corresponds with a 450°F regenerative heat exchanger outlet temperature. This temperature would be expected if letdown flow was at its maximum value and charging flow was at its minimum.

The back pressure regulating valves (CV-201P and CV-201Q) are automatically modulated by a pressure error signal that is derived by comparing an operator adjusted setpoint (normally 460 psig) and letdown heat exchanger outlet pressure.

During normal operation, only one (1) of the two (2) back pressure regulating valves is in service with the other valve in standby. A selector switch located in the control room is used to place either or both valves in service.

The piping on the downstream side of the pressure regulating valves is protected against over pressure by the low pressure letdown relief. The relief valve is set at 205 psig and relieves to the waste processing system.

An orifice is located in the piping downstream of the back pressure regulating valves and is used as the primary element for control room letdown flow indication.

5.2.7 Boronometer and Radiation Monitor

The boronometer and radiation monitor are installed to provide the operator with indications of RCS boron concentration and activity levels in the reactor coolant.

The boronometer (Figure 5-3) consists of a one (1) curie plutonium-beryllium neutron source and four (4) boron triflouride (BF3) detectors. A portion of the letdown flow (~1 gpm) is directed between the neutron source and neutron detectors. Since boron is a neutron absorber, the number of neutrons reaching the detector and the neutron detector's output is inversely proportional to RCS boron concentration.

The boronometer has a range of 0-2050 ppm with an accuracy of + 35 ppm. The accuracy of the boronometer is affected by temperature; therefore, if letdown temperature increases to 145°F, the boronometer is automatically isolated by closing boronometer-radiation monitor isolation valve (CV-521).

A radiation monitor parallels the boronometer. The monitor is designed to monitor gross activity and iodine (I-135) activity. Trends in the values of these two activities aid the operator in determining the cause of RCS activity changes. As an example, if a crud burst occurred, gross activity would increase significantly as compared with changes in I-135 levels. However, if a fuel failure occurs, I-135 activity will increase above its previous steady state values.

The radiation detector is a sodium iodide scintillation detector that supplies a local preamplifier. The output of the preamplifier supplies a linear circuit that supplies the indication of I-135 activity and to a logarithmic circuit that supplies gross activity indication.

The sample flow through the boronometer and radiation monitor rejoins the letdown stream downstream the letdown filters.

5.2.8 Letdown Filters

The letdown filters are installed to provide mechanical purification of the RCS. The filters are of the wound cartridge design and will provide a 98% retention of particles whose size exceeds 3 microns.

Normally one of these two filters is in service and the other is in standby. Locating these filters upstream of the ion exchangers prevents excessive crud deposition, along with its associated radioactivity, in the ion exchangers.

5.2.9 Ion Exchangers

Three ion exchangers are incorporated into the design of the CVCS. Two of these ion exchangers function to purify the RCS by soluble ion removal while the third ion exchanger is used to reduce the RCS boron concentration.

Regardless of the ion exchanger's function, each ion exchanger is filled with millions of resin beads. Each resin bead consists of two (2) principle parts; an inert, insoluble matrix, and a chemically active functional group. The matrix is a complex organic polymer that serves as an insoluble unit to which ions can be attached and thus be removed from solution. The functional group is exchanged for the ions that are removed from solution. Two (2) different types of functional groups are required if both positive and negative ions are to be removed. The first type is called a cation and will replace metallic ions with hydrogen ions. The second functional group exchanges its hydroxide ion for negatively charged impurities and is called anion resin.

At high temperatures, the resin beads will lose their ability to remove impurities from the RCS and, in fact, may release the undesirable ions that were previously exchanged. Therefore, if letdown heat exchanger outlet temperature reaches 145°F, the ion exchangers are automatically bypassed by repositioning the ion exchanger inlet valve (CV-520). Both the boronometer and radiation monitor inlet valve (CV-521) and the ion exchanger inlet valve (CV-520) must be manually repositioned after letdown temperature has been reduced to less than 145°F.

As previously stated, two different functions are performed by the ion exchangers. The purification function is performed by the two mixed bed ion exchangers. These ion exchangers contain anion and cation resin in a three (3) to one (1) ratio. The ion exchange process removes fission products to help maintain RCS activity within technical specification limits. The second function is to remove ions such as chlorides and fluorides which are responsible for RCS corrosion. One mixed bed is normally in service with the second unit in standby. The standby unit will be placed in service when the first unit loses its purification efficiency.

The deborating ion exchanger functions to reduce RCS boron concentration from 30 ppm to end of life concentrations. At low RCS boron concentrations, the dilution volume and the time required to change RCS boron concentration become excessive. The deborating ion exchanger contains only anion resin and directing letdown flow through this ion exchanger will reduce the RCS boron concentration.

Each ion exchanger tank contains internal resin bead retention elements; however, it is possible for broken beads (resin fines) to pass through the retention elements and into the letdown stream. Should this occur, the letdown strainer will collect the beads and prevent their entry into the volume control tank.

5.3 Volume Control Tank

The 3,880 gallon capacity VCT collects letdown and RCP CBO, provides a method of adding hydrogen to the RCS, interfaces with the waste processing system (WPS), interfaces with the reactor makeup system, and provides the normal suction source for the charging pumps.

5.3.1 Letdown Collection

Letdown flow into the volume control tank is governed by the volume control tank inlet valve (CV-500). The VCT inlet valve is a three (3) way valve that has one (1) inlet port and two (2) outlet ports. The letdown is supplied through the inlet and normally passes through the outlet port that supplies the VCT. In this mode of operation, the letdown enters the VCT and is returned to the RCS by the charging pumps. However, should the level in the VCT exceed the high level setpoint (88%), the VCT inlet valve will direct the letdown stream to the waste processing system (WPS). When the VCT level decreases to less than 87%, letdown flow is returned to the VCT.

Two normal plant evolutions will cause a high level condition in the VCT. The first is a heatup of the RCS. As the RCS temperature is increased, volumetric expansion causes an increase in pressurizer level. In order to maintain pressurizer level in the desired band, the operator manually increases letdown flow. With constant charging flow and an increased letdown flow, VCT level rises causing the VCT inlet valve to direct letdown to the WPS. This operation will be repeated many times during the startup. The expansion of the RCS, due to a heat up from cold shutdown to hot standby, results in a 20,000 to 30,000 gallon influent into the WPS.

The second evolution that will cause an increase in VCT level is a large dilution of the RCS. During dilutions, the reactor makeup system supplies demineralized water to the VCT. This addition of water, combined with letdown flow, causes VCT level to rise. When the VCT inlet valve diverts, RCS water with a higher concentration is directed to the WPS while the charging pump(s) delivers water with a low boron concentration to the RCS. Large dilutions will be required to lower RCS boron concentration so that criticality can be achieved at the desired rod position, to compensate for the power coefficient as power is escalated to 100%, and to compensate for changes in xenon concentration.

In addition to collecting letdown, the VCT also receives the CBO flow from the RCPs. Individual bleed off lines are piped together and exit the containment building via redundant isolation valves (CV-505 and CV-506). The isolation valves are air-operated and are automatically closed by a SIAS. In the event of a SIAS, the CBO is diverted to the quench tank through relief valves.

5.3.2 Hydrogen and Waste Gas Interfaces

During power operations, the gas space of the VCT is pressurized with hydrogen which is absorbed by the incoming letdown flow. The coolant, containing the absorbed gas, is charged into the RCS where the radiation from the core causes the hydrogen to combine with free oxygen. The scavenging of free oxygen minimizes RCS corrosion. Hydrogen is added to the VCT from the plant hydrogen storage banks via a pressure regulating valve. Hydrogen pressure is maintained between 20-40 psig.

If maintenance is to be performed on the VCT during shutdown periods, the explosive hydrogen must be purged from the tank. This can be accomplished by venting the gas space of the VCT and adding nitrogen to purge out the hydrogen. This procedure must be reversed prior to startup because the addition of nitrogen to the RCS at power will cause the formation of corrosive nitric acid.

In addition to hydrogen, fission gases are found in the gas space of the VCT. These gases come out of solution as the letdown flows into the tank. The fission gases may be vented to the waste gas system by the operator.

5.3.3 Waste Processing System Interfaces

The automatic level diversion input into the WPS that was discussed in section 5.3.1 supplies an input of radioactive water to the WPS. The input of letdown into the WPS normally enters the vacuum degassifier where fission gasses are removed. The fission gases are piped to the waste gas system, and the water effluent from the vacuum degassifier is transferred to the RCS waste receiver tanks.

5.3.4 Charging Pump Suction Supply

The letdown that is collected in the VCT serves as a suction supply for the charging pumps. The VCT outlet valve (CVC-501) is located in the charging pump supply and receives two automatic control signals. First, the valve is interlocked closed on low-low VCT level (5.6%). At the same time, the charging pump suction supply valve (CVC-504) opens to supply a source of water from the refueling water tank (RWT) to the charging pumps.

The VCT level interlock on these valves insures that a suction source is always available to the charging pumps. The VCT outlet valve also receives an automatic close signal from SIAS.

The piping between the VCT and the charging pump suction header contains penetrations from the concentrated boric acid storage tanks, the RWT, and the chemical addition tank.

5.3.5 Chemical Addition

The chemical addition tank has a capacity of eight (8) gallons and is used to add lithium hydroxide or hydrazine to the RCS. Lithium hydroxide maintains the pH of the RCS in the basic region thus minimizing corrosion. Hydrazine is added to scavenge oxygen when the plant is in cold shutdown.

5.3.6 Relief Valves

Two relief valves are associated with the VCT and the charging pump suction header. A relief is installed on the gas space of the VCT and has a setpoint of 70 psig. The relief valve discharges to the plant vent header. The second relief is installed on the suction supply to the charging pumps and has a setpoint of 80 psig. This relief valve discharges to the waste receiver tank. Both relief valves are installed to prevent over pressure conditions in this section of the CVCS.

5.4 Charging System

The functions of the charging system are to return the purified coolant from the VCT to the RCS and to add coolant to the RCS during an accident. The suction for the charging pumps during an accident is the concentrated boric acid storage tanks.

5.4.1 Charging Pumps

Three (3) positive displacement charging pumps are installed to perform the design functions of the charging system. Each pump has a capacity of 44 gpm and is motor driven. The 11 and 12 pumps are powered from their respective 480 Vac class 1E electrical distribution systems, while the 13 pump may be powered from either 480 Vac class 1E train.

The charging pumps are triple plunger pumps. Each plunger has a diameter of two and one-eight (2 1/8) inches and a stroke of five (5) inches. The pump design pressure is 2800 psig, and the design temperature is 250°F. The pump is manufactured from 316 stainless steel. A 100 hp motor serves as the pump driver. Reduction gears reduce the speed of the motor to 210 rpm.

The charging pumps are equipped with a packing lubrication system that injects water into the packing area of the pump. This system consists of a small tank that gravity feeds the packing area and functions to extend the packing lifetime.

Pump discharge relief valves are installed to prevent shutoff operations of the positive displacement pumps. The valves are set at 2800 psig and have a capacity of 44 gpm.

During normal operations, only one (1) pump is in service with the other two (2) pumps in standby. The standby pumps are controlled by pressurizer level. If pressurizer level drops to a predetermined value, the first standby charging pump starts. If the increase in charging flow fails to stop the pressurizer level decrease, the second standby charging pump will start. A selector switch in the control room determines the order of charging pump operation. During emergency situations, all charging pumps are started by a SIAS signal. From the discharge of the charging pumps, the water flows to the shell side of regenerative heat exchanger.

5.4.2 Charging Supplies

The charging stream passes through the shell side of the regenerative heat exchanger where it is preheated to minimize the thermal shock to the RCS charging penetrations and then travels to the charging connections on the discharge of reactor coolant pumps 11A (CV-519) and 12B (CV-518) and, if required, to the auxiliary pressurizer spray line (CV-517).

The first two (2) connections are normally open and return the coolant to the RCS. A spring-loaded check valve is in parallel with the charging supply to the discharge of RCP-11A (CV-519). The check valve insures that a discharge path for the charging pumps is always available.

The third connection is the auxiliary spray to the pressurizer and is used to decrease pressurizer pressure during cooldowns and other periods when the RCPs are not running. When auxiliary spray is used, the possibility of thermal shock exists. The temperature difference between the pressurizer and spray fluid is limited to 400°F by plant technical specifications. If the 400°F ΔT limit is exceeded, then the value of ΔT is logged and a total usage factor is maintained as a part of plant records. The spray to pressurizer ΔT is computed by subtracting regenerative heat exchanger charging outlet temperature from pressurizer steam space temperature.

5.4.3 HPSI Check Valve Testing

A supply line from the common charging pump discharge to the high pressure safety injection (HPSI) system is provided to test the operability of the safety injection loop check valves. At normal operating pressures, the HPSI pump discharge pressure (~1400 psia) is too low to provide a flow through the check valves and into the RCS; therefore, the charging pumps may be used to provide the flow into the RCS. If one is able to obtain flow into the RCS with the charging pumps, the safety related check valve is open and can be considered operable.

5.5 Soluble Poison Control (Figure 5-4)

Boric acid is dissolved in the reactor coolant and is used for reactivity control. If negative reactivity additions are required, then the boron concentration is increased by the addition of boric acid. Conversely, the addition of pure water dilutes the RCS boron concentration and adds positive reactivity. Also, the compensation for VCT level changes due to normal leakage are made by the addition of both pure water and boric acid while maintaining a constant RCS boron concentration. These basic design requirements are satisfied by the boric acid and reactor makeup water systems.

5.5.1 Boric Acid System

The boric acid makeup system consists of two concentrated boric acid storage tanks, two boric acid pumps, and the necessary control valves for the addition of boric acid during emergencies and normal operations.

The concentrated boric acid storage tanks have a capacity of 9500 gallons and contain enough boric acid to ensure that 1% ΔK/K shutdown margin can be maintained if the plant is cooled down from normal operating conditions to less than 200°F and xenon free conditions exist at cold shutdown. The boric acid concentration in the tanks is approximately 12700 ppm.

Motor operated valves (CV-508 and CV-509) provide concentrated boric acid to the suction of the charging pumps. These gravity feed valves are automatically opened by a SIAS.

The tanks also supply concentrated boric acid to the CVCS via the boric acid pumps. The boric acid pumps are single-stage centrifugal pumps that are capable of supplying 143 gpm at design conditions. A recirculation flow of fluid through each pump is maintained at 10 gpm. The pumps are powered from the class 1E 480 Vac distribution system. Both pumps are started by a SIAS and discharge to the suction of the charging pumps through motor operated valve CV-514 which also receives a SIAS.

This path is redundant to the gravity feed path discussed earlier. The flow rate through either the gravity feed or pump discharge addition path is in excess of the 132 GPM requirement of three charging pumps. Recirculation valves (CV-510 and CV-511) are installed to provide a sufficient flowpath for the pumps in non-accident mode of operations. These valves are closed by a SIAS.

In addition to the accident supply, the boric acid pumps supply boric acid to the CVCS for soluble poison concentration control. The boric acid flow control valve (CV-210Y) supplies boric acid to the VCT via the makeup stop valve (CV-512). The boric acid flow control valve will open in the borate or automatic modes of the makeup mode selector switch.

The boric acid addition rate (30 gpm maximum) in the borate mode of operation will result in a 6 ppm/minute rate of change of RCS boron concentration. Certain transients and accidents require a faster rate of change of boron concentration. An anticipated transient without scram (ATWS) is an example of such a situation. An ATWS is caused by some common mode failure that prevents the reactor protection system (RPS) from inserting the CEAs when a valid trip condition exists. Since the CEAs cannot shut down the reactor, boric acid must be used. If an ATWS occurs, the plant operators will add boric acid via the gravity feed valves or through CV-514. The rate of change of RCS boric acid concentration in this mode of operation is approximately 26 ppm/minute.

5.5.2 Demineralized Water Supply

The demineralized water supply consists of a supply of demineralized water from the demineralized water system, reactor coolant makeup water pumps (RCMU pumps), and associated valving. The demineralized water tank is a 350,000 gallon capacity tank that is filled by the plant makeup demineralizers and serves as the storage reservoir for reactor makeup water.

The RCMU pumps are motor-driven, single stage centrifugal pumps that supply reactor makeup water to the CVCS. Since the ability to dilute the RCS is not safety related, the reactor makeup water pumps are powered from non-vital 480 Vac.

The reactor makeup flow control valve (CV-210X) supplies demineralized water to the VCT via the makeup stop valve (CV-512). The reactor makeup flow control valve will open in the dilute or automatic modes of the makeup mode selector switch.

5.5.3 Makeup Control System

The makeup control system contains a mode selector switch, flow controllers, batch controllers, and the control valves described in Sections 5.5.1 and 5.5.2. The mode control switch is a four (4) position selector switch that is located in the control room and determines the position of the control valves in the makeup system. Two (2) flow controllers are provided to determine the addition rates of boric acid and reactor makeup water by controlling the position of boric acid flow control valve (CV-210Y) and reactor makeup flow control valve (CV-210X).

When a dilution or boration is to be performed, the operator sets in the desired quantity into the batch controllers. As the fluid passes through the flow elements, a signal is also sent to the batch controllers. When the quantity of added solution equals the operator's setpoint, the boration or dilution is terminated by the batch controllers. The batch controllers along with the flow controllers and mode selector switch provide signals to the control valves in the makeup system.

The operation of these devices will be described by discussing the borate, dilute, auto and manual positions of the mode selector switch .

1. In the borate position of the mode selector boric acid flow control valve (CV-210Y) will open to supply concentrated boric acid to the VCT via the makeup stop valve (CV-512). To borate, the operator selects an addition rate, a batch size, opens the makeup stop valve, and

positions the mode selector switch to the borate position. The selected boric acid pump will start, CV-210Y will control the addition rate of boric acid into the system. When the quantity of boric acid equals the batch size placed into the boric acid batch controller, CV-210Y closes and the boric acid pump stops.

2. In the dilute position of the mode selector the reactor makeup flow control valve (CV-210X) and makeup stop valve CV-512 open to supply demineralized reactor makeup water to the VCT. To dilute, the operator selects an addition rate, a batch size, and positions the mode selector switch to the dilute position. The selected reactor makeup water pump will start, CV-210X will control the addition rate of reactor makeup water, and CV-512 will be manually opened to complete the flowpath to the VCT. When the batch has been added, the reactor makeup water batch controller will close reactor makeup flow control valve (CV-210X) and stop the reactor makeup water pumps. The makeup stop valve will be manually closed.

3. In the auto position of the mode selector VCT level controls the makeup system. If VCT level decreases to 72%, the makeup system will restore the level to 86%. This evolution is accomplished by opening CV-210X, CV-210Y, CV-512, and sending a start to the boric acid and RCMU pumps. The concentration of the added solution is determined by the flow controller settings for boric acid and reactor makeup water.

4. The manual position of the mode selector allows the manual control of any control valve in the makeup system. Manual mode is normally used during makeup of the RWT.

5.6 Engineered Safety Features Operations

The changes that occur in the CVCS upon the receipt of an engineered safety features signal are:

1. Letdown is isolated,
2. The VCT outlet valve is closed,
3. All three charging pumps start,
4. Both boric acid pumps start,
5. The gravity feed addition valves open,
6. The boric acid discharge valve (CVC- 514) opens to direct the discharge of the boric acid pumps to the charging pump suction,
7. Boric acid pump recirculation valves close and
8. RCP CBO valves close.

The above actions isolate the non-vital letdown line and inject concentrated boric acid into the RCS via the normal charging paths; however, safety analysis does not take credit for the addition of the CVCS during accidents. Operator actions are required to stop the boric acid makeup and charging pumps prior to emptying the concentrated boric acid storage tanks.

5.7 Summary

The CVCS is a major auxiliary system that functions to control RCS inventory, to maintain RCS chemistry, and to control the soluble poison concentration of the RCS. In addition, the CVCS supplies borated water to the RCS in the event of an accident.

Major system interfaces include the pressurizer level control system which varies letdown or charging flow based upon pressurizer level error, the WPS which receives its influent from the letdown system, and the makeup system that provides methods of soluble poison control.

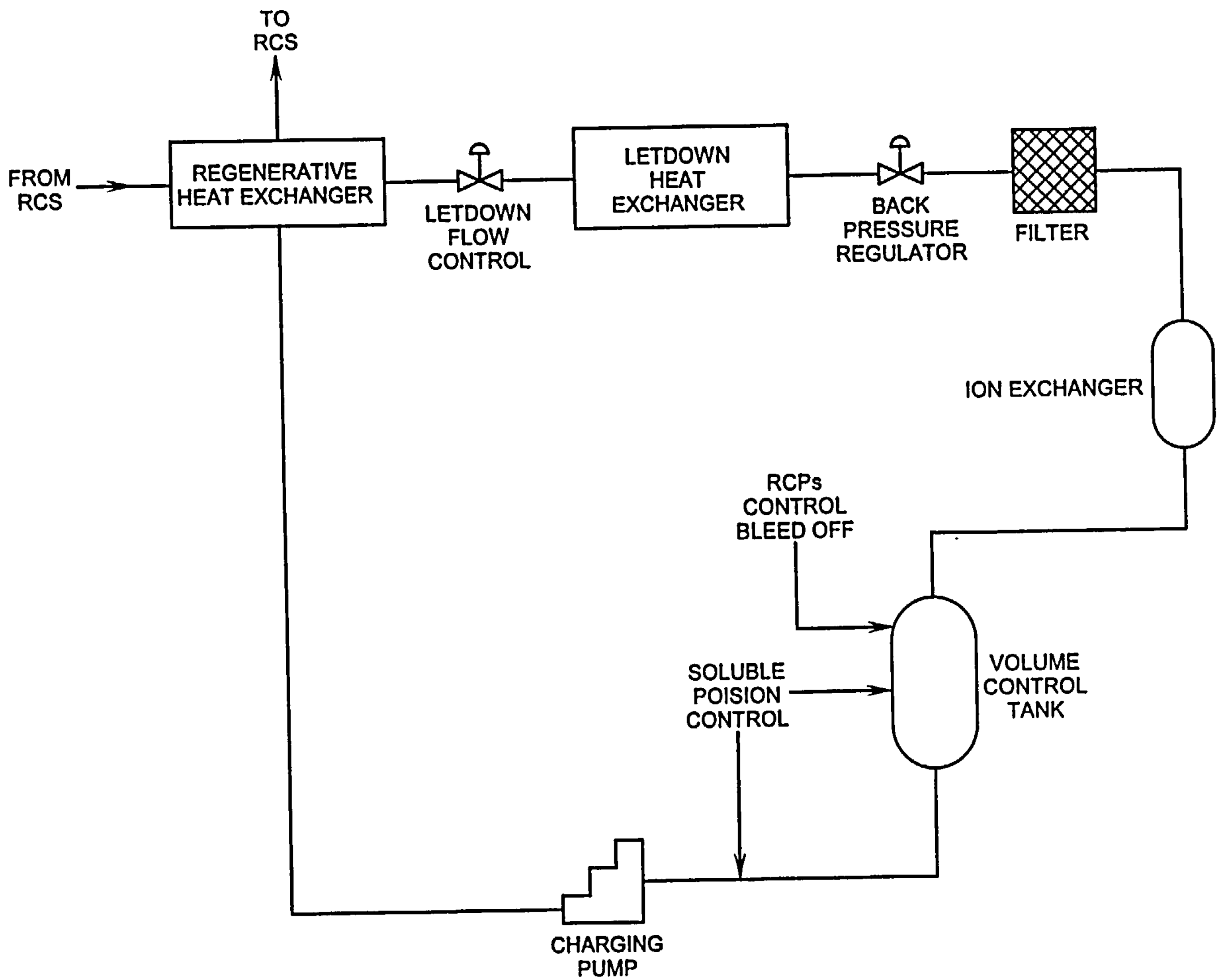

Figure 5-1 Simplified Chemical and Volume Control System

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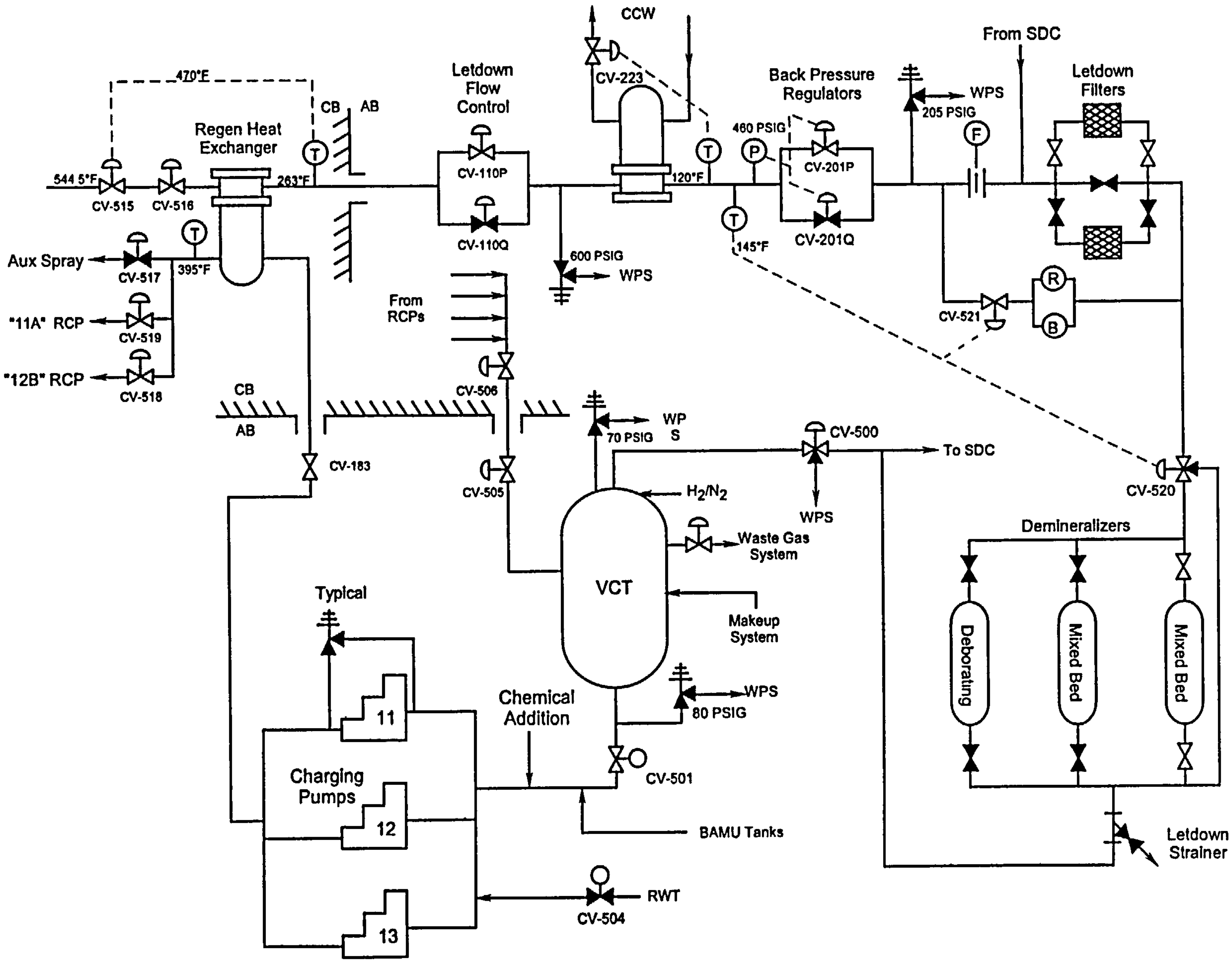

Figure 5-2 CVCS Diagram

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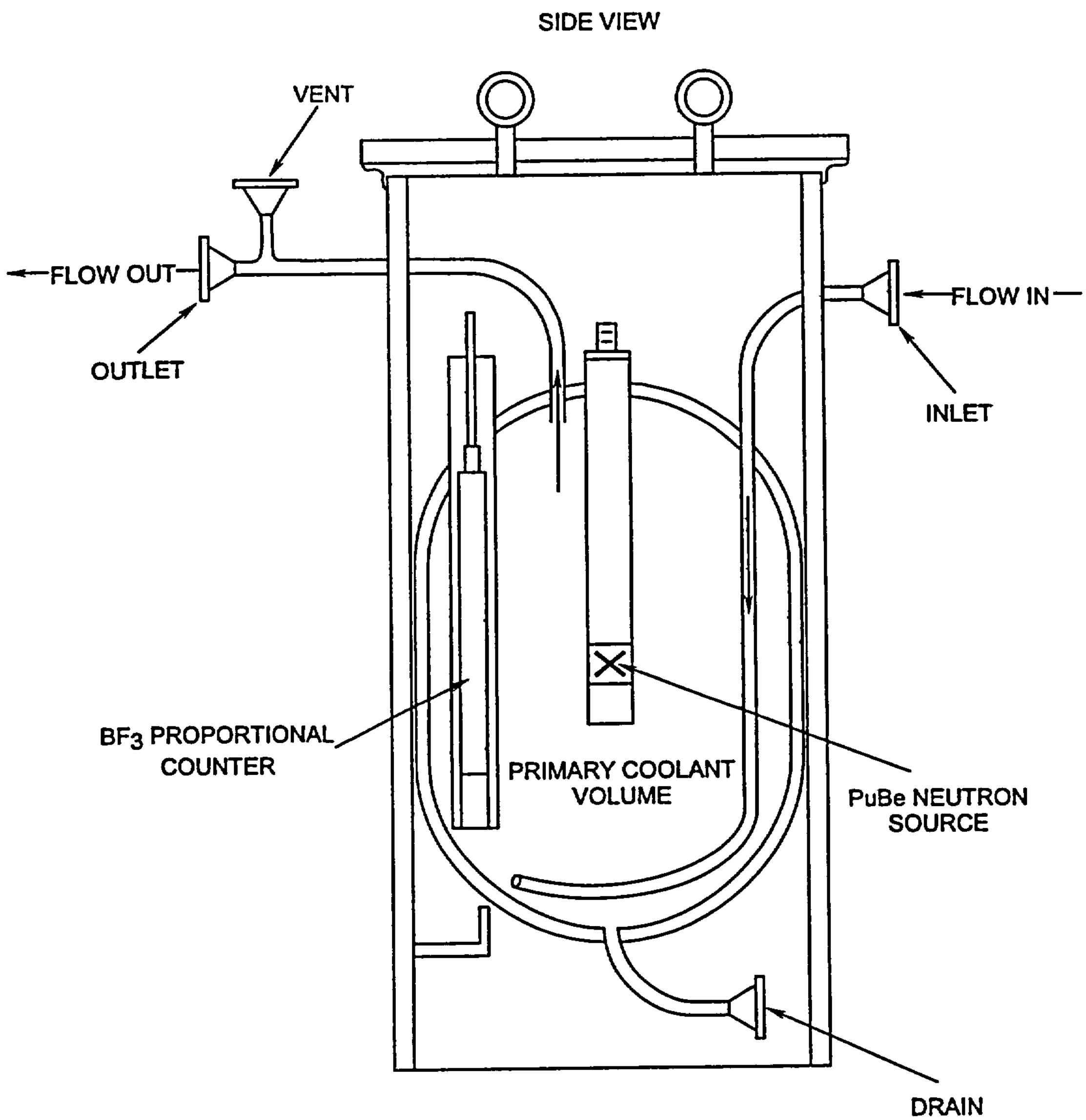

Figure 5-3 Boronometer Assembly

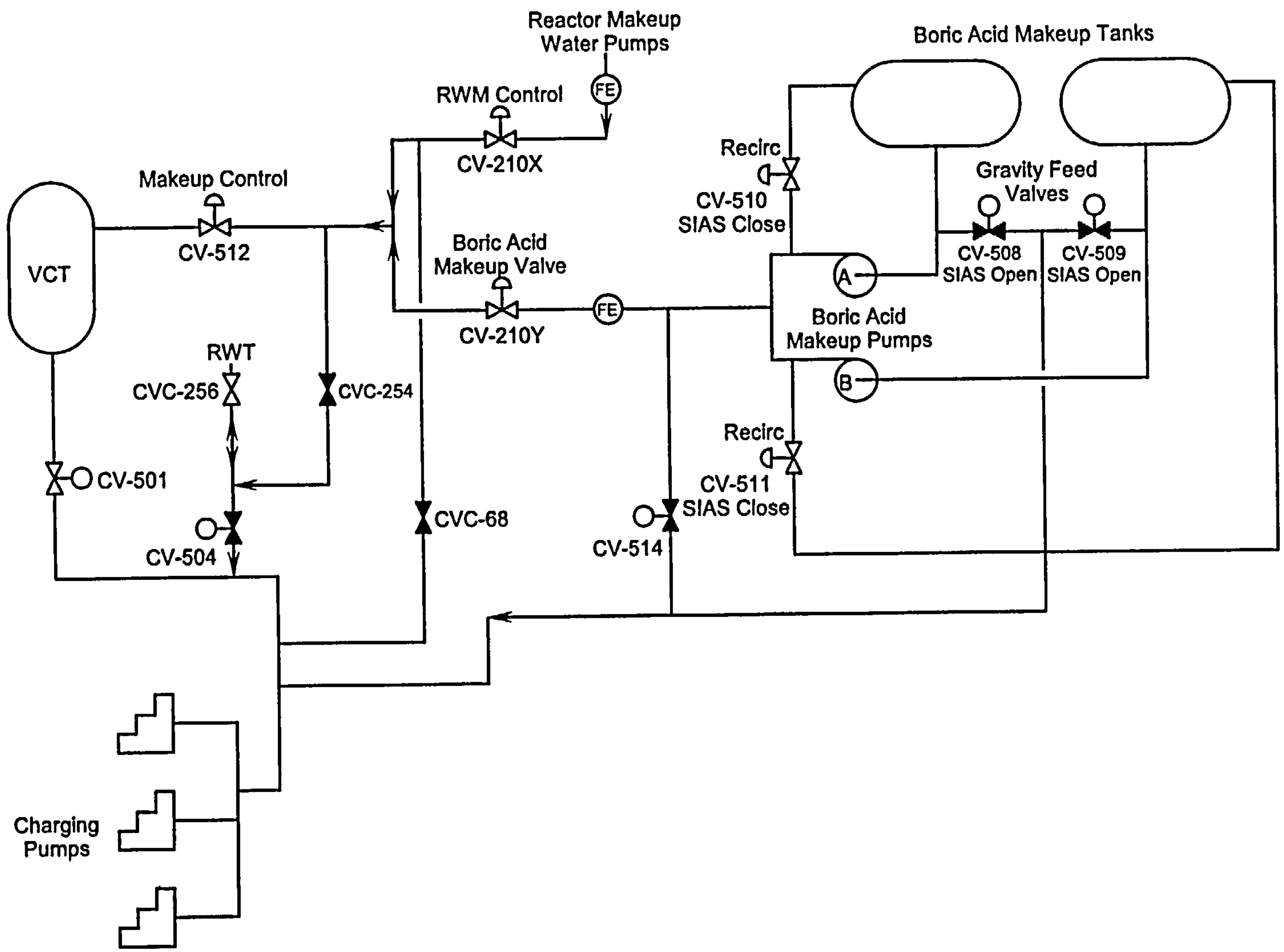

Figure 5-4 Makeup Control System

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Chapter 6

PRESSURIZER CONTROL SYSTEMS

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6.1 PRESSURIZER PRESSURE CONTROL

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6.1 PRESSURIZER PRESSURE CONTROL SYSTEM

Learning Objectives:

1. State the purposes of the pressurizer pressure control system (PPCS).

2. List the sequence of actions performed by the PPCS for an increasing or decreasing pressure control signal.

6.1.1 Introduction

The purpose of the PPCS is to:

1. Maintain RCS pressure at 2250 psia,

2. Minimize pressure excursions during transient operations,

3. Provide pressure signals for indication and alarms and

The system consists of a combination of heater banks and spray valves actuated at the proper times by a pressure controller. The heaters and spray valves are set to operate at various fixed pressure deviation points from the controller set point.

During steady state conditions, approximately one half the pressurizer volume is saturated water and the remainder is saturated steam. The pressure control system is capable of affecting this steam volume sufficiently during design transient conditions such that a reactor trip will not result.

The pressurizer heaters are divided into two (2) groups consisting of two (2) banks of proportional heaters and six (6) banks of backup (on-off) heaters. These heaters maintain the equilibrium heat balance in the pressurizer during steady state conditions. If system pressure decreases significantly from the set point, the proportional heaters would provide maximum heat output and, in addition, the backup heaters would be energized on. For a system pressure increase above the normal set point, all heaters would be deenergized and the spray valves would be opened (proportionally over a fixed pressure range) to admit cooler RCS water into the pressurizer steam volume.

6.1.2 System Description

Figure 6.1-1 is a functional block diagram of the pressurizer pressure control system. Two (2) separate pressure channels are provided for control of pressurizer pressure. A pressure detector transmits a signal proportional with pressurizer pressure to two (2) bistables and a pressure indicator controller. A channel selector switch determines which channel bistable and pressure transmitter outputs are used for the various control functions.

The pressurizer pressure control station provides manual to automatic and automatic to manual transfer capability as well as the manual control capability for the modulating control of the proportional heaters. It provides the set point adjustment for the modulating automatic control and displays both the set point and the selected pressurizer pressure signal.

The output from the pressure indicator controller will be the difference between the set point and the measured pressure of the pressurizer when in automatic, or the value set by the operator when in manual. Figure 6.1-2 shows the pressure controller output compared to the pressure deviation. This signal will be sent to the selected spray valve electro-pneumatic controller and to the proportional power control unit. As the pressure controller output increases from 0% to 40%, the power supplied to the proportional heaters will go from full power to zero power. As the output of the pressure controller increases from 60% to 100% the output of the spray valve controller, if in auto, will increase from 0% to 100%. This will stroke the selected spray valve from full closed to full open.

Pressure indication for each channel is provided on the pressure indicator controllers and on a two pen recorder. Range of pressure indication is 1500 psia to 2500 psia. A dual-action bistable provides a pressurizer pressure channel pressure alarm for each channel. A common alarm window annunciates if either bistable actuates.

6.1.2.1 Heater Operation

Six (6) banks of independently powered immersion heaters are available to add energy to the pressurizer to increase the RCS pressure. Heater banks 1 and 2 are assigned to be controlled proportionally. They are designed to be at least 200% greater than the system heat losses with the spray bypass valves open.

The pressurizer pressure indicating controller sends a control signal to the proportional heater and spray valve controllers. This analog control signal is proportional to the actual pressure deviation from the controller set point. The proportional heaters operate in a 50 psia range around the controller set point. Normally, these heaters are at half power in the middle of the control band.

There are two banks of proportional heaters each having a capacity of 150 kW. A three position hand switch (off, on, and auto) operates a breaker to supply power to selenium control rectifiers. These rectifiers vary the power to the proportional heaters in response to the control signal from the selected pressure indicating controller. Maximum power is supplied when pressurizer pressure is 2225 psia, and minimum power is supplied when pressurizer pressure is 2275 psia. A low level in the pressurizer will open the supply breakers to the proportional heater selenium control rectifiers and the backup heaters.

The remaining heater banks are designated as backup heaters, and are either on or off, unlike the variable output capability of the proportional heaters. A bistable in the selected pressurizer pressure control channel is set to energize the four backup heater banks at a decreasing pressure (2200 psia) and to deenergize them at an increasing pressure (2225 psia), provided that the backup heater control switches are in the automatic position. Each bank of backup heaters has a capacity of 300 kW.

Backup heater banks may also be operated from the remote shutdown panel. A high pressurizer level deviation of three and six-tenths percent (+3.6%) from programmed level will energize the backup heaters if the heater control switches are in automatic (section 6.2). A low pressurizer level of 28% will de-energize the backup heaters. An indication light for each bank of heaters is mounted on the main control board to provide indication to the operator whenever the circuit breaker of the bank is closed.

6.1.2.2 Spray Valve Operation

The output of the selected pressure indicating controller is also sent to the spray valve controller. The spray valve controller is set to start opening the spray valves when the input reaches 2300 psia. The spray valves will be fully open when the input reaches 2350 psia. The operator can take manual control of the spray valve controller and position the valves at any desired position.

A single spray nozzle, supplied by two (2) parallel valves, is available to reduce pressure. The spray coolant is taken from the discharge lines of two (2) of the four (4) reactor coolant pumps (RCPs), both from the same steam generator. A total minimum spray flow capacity of 375 gpm is available from the two (2) spray valves under design conditions. Under design conditions, each 1 gpm spray flow corresponds to approximately 18 kW of heat loss.

Each spray control valve has an associated small capacity bypass valve. They are adjusted locally to supply a minimum flow through the spray lines and spray nozzle in order to maintain the temperature of the spray piping and to provide continuous trim for the pressurizer heat balance. In steady state, heat must be added to the pressurizer to compensate for the heat loss through the vessel walls (approximately 42.5 kW), and for the heat defect introduced by the continuous spray flow (approximately 1.5 gpm corresponding to 27 kW).

6.1.3 Normal Operation

Assuming an initial controller set point of 2250 psia, and an initial pressure of 2225 psia, the proportional heaters will be at full power at 2225 psia and zero power at 2275 psia. The selected spray valves will start to open at 2300 psia and will be fully open at 2350 psia.

6.1.4 Summary

The pressurizer pressure control system maintains the RCS pressure at or near 2250 psia. The system uses heaters and spray valves which are actuated when actual pressure deviates from the desired set point.

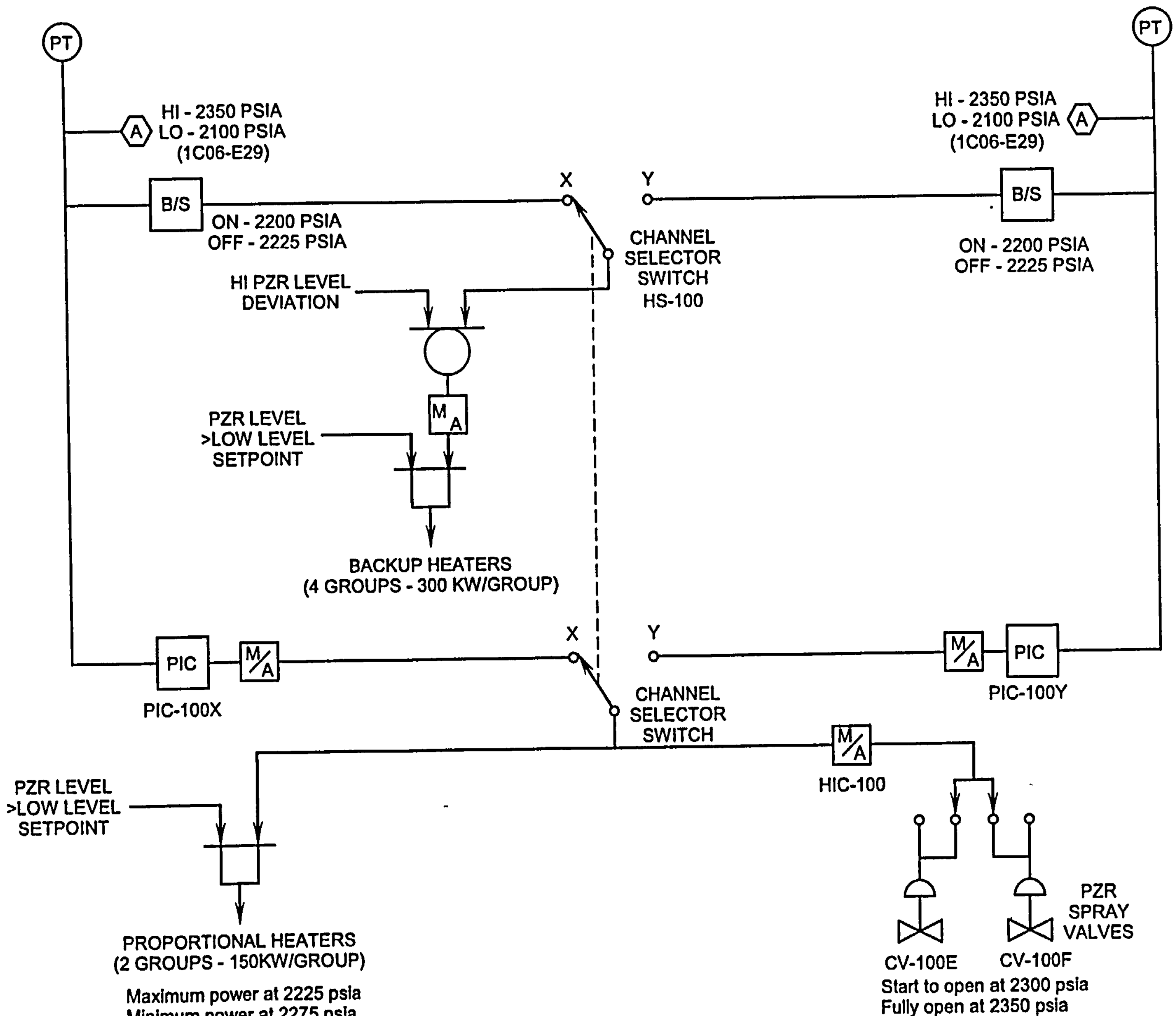

Figure 6-1-1 Pressurizer Pressure Control System

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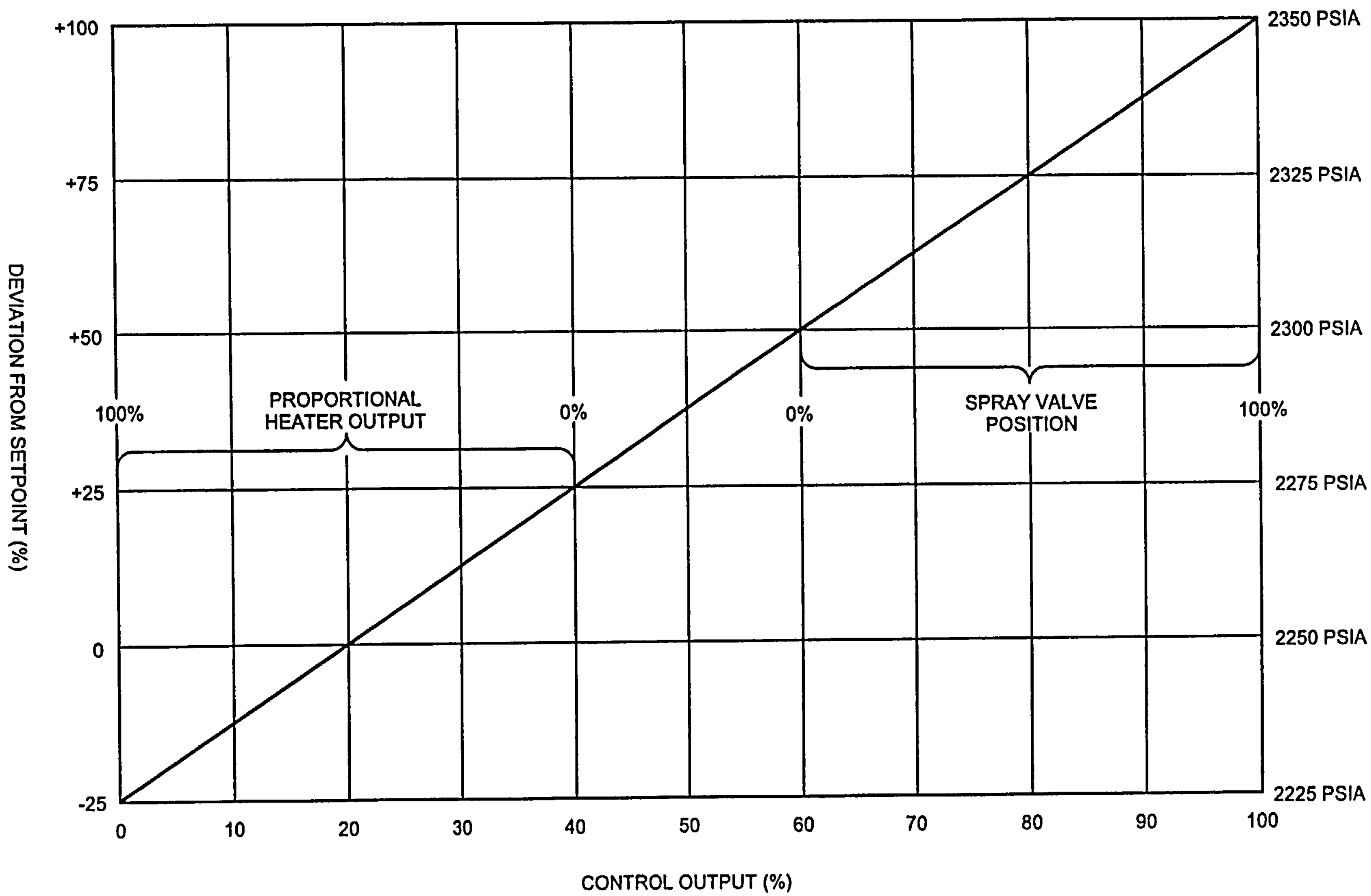

Figure 6.1-2 Pressurizer Pressure Control Output vs. Pressure Deviation

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6.2 PRESSURIZER LEVEL CONTROL

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6.2 PRESSURIZER LEVEL CONTROL SYSTEM

Learning Objectives:

1. State the purpose of the pressurizer level control system (PLCS).
2. List the purpose of each PLCS input.
3. Explain the reason pressurizer level is programmed.
4. List the devices that are controlled by pressurizer level.
5. Explain the purpose of the pressurizer low level interlock.

6.2.1 Introduction

The pressurizer is designed to accommodate the changes in reactor coolant system (RCS) volume that are caused by changes in RCS temperature. The pressurizer is not large enough to accommodate the total increase in volume resulting from the change in Tavg occurring from 0% to 100% power (532°F to 572.5°F).

The design of the containment must take into account the volume of the RCS. In general, the larger the RCS volume the bigger the containment must be in order to accept the pressures that result from a loss of coolant accident. The maximum size of the pressurizer is limited by the containment building design and, therefore, cannot accommodate the entire expansion volume resulting from the temperature change which occurs from 0% to 100% power.

However, if the pressurizer volume is too small the pressure changes associated with a change in temperature could be unacceptable. For example, the temperature change associated with a loss of load transient could result in filling the pressurizer and reaching an associated high pressure condition. Or, the decrease in temperature following a reactor trip could empty the pressurizer resulting in an unnecessary initiation of safety systems by a low pressurizer pressure signal. The pressurizer design volume is a compromise between these two limits.

A minimum volume of 40% must exist in the pressurizer to allow the unit to be maneuvered at the design rates at low power levels. The design maneuvering rates are a 5% per minute ramp or a 10% step load change. As shown in Figure 6.2-1, if pressurizer level is at its minimum and charging and letdown are maintained at equal values and power is escalated from 0 to 100%, the expansion volume would result in an unacceptable high level. In fact, the pressurizer would be almost completely filled with water. Any temperature increases from this point would completely fill the pressurizer and cause a large unacceptable increase in RCS pressure.

The 100% level of 60% is based on accepting a load rejection from 100% power without the pressurizer going solid and accepting the cooldown associated with a reactor trip without initiating a safety signal. If a power decrease from 100% to 0% is made with the pressurizer at 60% level and charging and letdown maintained at equal values, the pressurizer would be emptied. The pressurizer level control program is a compromise between these two extremes. The purpose of the PLCS is to control pressurizer level at the desired setpoint.

6.2.2 Pressurizer Level Control System Inputs

The desired value of pressurizer level is generated as a function of average coolant temperature in the reactor regulating system (RRS). The level setpoint from the selected RRS is supplied to the PLCS. A manual/automatic control station is installed in the signal path to allow the operator to manually supply the setpoint if desired. The setpoint is compared with actual pressurizer level as sensed by two pressurizer level transmitters. The result of the comparison is supplied to the pressurizer level control devices via a channel selector switch. As shown in Figure 6.2-2, two types of control signals are used. The first type of signal is an analog control signal generated by the proportional-integral-derivative (PID) controller. This signal is used to control the position of the letdown flow control valves and to start the standby charging pumps. The second signal type is supplied by bistables and is used to control the pressurizer heaters and to provide backup start and stop signals for the charging pumps.

6.2.3 Pressurizer Level Control Devices

6.2.3.1 Letdown Flow Control Valves

The output of the selected PID controller is supplied to the letdown flow control valves. Normally only one (1) of the two (2) letdown flow control valves is used to control letdown flow. When pressurizer level is at setpoint, the selected letdown flow control valve is positioned to allow a letdown flow rate of 40 gpm. If pressurizer level increases above setpoint, the output of the PID controller will increase letdown flow by positioning the letdown flow control valves. As shown on Figure 6.2-3, letdown flow will increase from 40 gpm when the pressurizer is at its level setpoint to a maximum of 128 gpm when level increases to nine and one-tenth percent (9.1%) above setpoint. When pressurizer level decreases below setpoint, the selected PID controller will decrease letdown flow by closing the letdown flow control valves. Letdown flow will decrease from its normal value of 40 gpm to its minimum of 29 gpm as pressurizer level drops from its setpoint value to one and one-tenth percent (1.1%) below setpoint. It should be noted that the operator can control the letdown flow rate by taking manual control of the selected PID controller. Also, the limiter in the circuit for the letdown flow control valves is used to set the minimum and maximum values of letdown flow. The effects of the limiter can be bypassed if the operator positions the control station for the letdown flow control valves to manual.

6.2.3.2 Charging Pump Control

Three (3) positive displacement charging pumps are installed in the chemical and volume control system (CVCS) to supply normal RCS makeup requirements. Each pump has a capacity of 44 gpm. During normal operations, one (1) charging pump is in service with the other two (2) pumps in standby. Charging pump control is accomplished by five (5) control switches. Four (4) of these switches are used to determine the operating mode of the charging pumps, and the fifth switch is used to select the starting order of the standby charging pumps. The first four (4) switches (one (1) switch each for the 11 and 12 pumps and two (2) switches for the dual powered 13 pump) have three (3) positions; start, stop, and auto. The start and stop positions allow manual control of the pump while the automatic position allows the PLCS to control the operating status of the charging pumps. The last control switch is used to determine the starting order of the standby charging pumps. The switch has three positions (12&13, 13&11, and 11&12). In the 12&13 position, the 12 charging pump is the first standby charging pump and the 13 charging pump is the second standby charging pump. The control switch for the 11 charging pump would be in the start position and this pump would be supplying normal charging.

Two (2) bistables are located on the output of the PID controller. The first bistable will start the first standby charging pump if the deviation signal exceeds negative two and one-half percent (-2.5%). The second bistable starts the second standby charging pump when the level deviation exceeds negative three and six-tenths percent (-3.6%). The reset points for the bistables are negative one and one-tenth percent (-1.1%) and negative one and six-tenths percent (-1.6%) respectively.

In addition to the PID controller signal, the bistable portion of the PLCS also provides start and stop signals to the charging pumps. One (1) of the bistables is used to provide a backup start signal to both standby charging pumps if the level deviation exceeds negative four and one-tenth percent (-4.1%). This signal ensures that maximum charging flow is available to the pressurizer in the event of a controller failure. This bistable also provides a low pressurizer level alarm. The reset point for the bistable is negative two and seven-tenths percent (-2.7%). The second bistable provides a backup stop signal for the standby charging pumps on a high level deviation of positive three and six-tenths percent (+3.6%). The high pressurizer level alarm and pressurizer backup heater actuation is also provided by this bistable. The reset point for these actions is positive two and one half percent (+2.5%).

6.2.3.3 Pressurizer Heater Signals

The bistable portion of the PLCS provides two (2) signals that are used to control the pressurizer heaters. The first signal is the low level heater cutoff signal. This signal is set at 28% and prevents the heaters from being energized unless they are covered with water. This interlock is supplied from the level transmitters via an interlock defeat switch.

The interlock defeat switch allows the operator to remove a failed transmitter from the heater circuitry. The switch has three positions (x, both, and y). In the both position, the pressurizer heaters will be deenergized if either transmitter senses that the pressurizer level has decreased to 28%. These bistables also provide the low-low pressurizer level alarms. Alarm generation is independent of the position of the interlock defeat switch.

If pressurizer level increases to positive three and six-tenths percent (+3.6% above setpoint, a bistable in each channel will supply a high level deviation signal to the channel select switch. The selected channel will energize all pressurizer backup heaters. The reason for energizing the pressurizer heaters on a high level deviation is an anticipatory feature. The high level deviation is caused by an insurge of cold water into the pressurizer. The cold water will lower pressurizer temperature and pressure. The energy from the pressurizer heaters will raise the water to saturation temperature and minimize the pressure decrease. The reset point for this bistable is positive two and one-half percent (+2.5%).

6.2.3.4 High Level Alarm Generation

The last bistable in the PLCS is used to generate the pressurizer high level alarm. The alarm will be generated if pressurizer level deviation exceeds +10.8% and resets at +10.3%. The bistable setpoints are summarized on Figure 6.2-3.

6.2.4 System Operations

A reactor trip can be used to illustrate the operations of the pressurizer level control system. When the reactor trips, the steam dump and bypass control system (SDBCS) functions to decrease RCS temperatures to the no load Tavg value. As temperatures decreases, a pressurizer outsurge occurs. As pressurizer level drops below setpoint, the letdown flow control valves start to decrease letdown flow. When the deviation signal reaches negative one and one-tenth percent (-

1.1%) letdown flow is at its minimum value. Deviations of negative two and one-half percent (-2.5%) and negative three and six-tenths percent (-3.6%) will start the first and second standby charging pumps. If the deviation reaches negative four and one tenth percent (-4.1%), a backup signal to start both standby pumps will be generated.

As Tavg is decreased, the pressurizer level setpoint will be decreased. This action, combined with the additional charging flow, will start to restore pressurizer level to its desired value. As pressurizer level increases, the deviation from setpoint will decrease. At negative two and seven-tenths percent (-2.7%), the backup start signal and low pressurizer level alarm will reset. At negative one and six-tenths percent (-1.6%), the second standby charging pump will stop.

Next, at negative one and one-tenth percent (-1.1%), the first standby charging pump will stop. As the operating charging pump continues to raise pressurizer level, the letdown flow control valves will be positioned to control letdown at its normal value of 40 gpm.

Next, consider the response of the PLCS during a load decrease. Assume that the control element assemblies (CEAs) are in manual and the load decrease is to be accomplished by borating the RCS. If turbine load is reduced faster than boration can decrease reactor power, then Tavg will increase because of the energy mismatch. As Tavg increases, the insurge increases pressurizer level. As pressurizer level goes above setpoint, the output of the selected PID controller increases letdown flow. If the insurge creates a level deviation of positive three and six-tenths percent (+3.6%), the backup heaters will be energized. Carrying the transient to extremes for discussion purposes; when the pressurizer level deviation reaches positive nine and one-tenth percent (+9.1%) letdown flow will reach its maximum of 128 gpm. At +10.8%, the high level alarm will annunciate. As the increase in letdown flow starts to restore level to normal, the following actions will occur:

1. At +10.3%, the high level alarm will reset,

2. As the error decreases below +9.1%, the letdown flow control valves will start to throttle down,

3. As level drops below +2.5%, the backup heaters are returned to pressure control and

4. Letdown flow is returned to 40 gpm when level reaches setpoint.

For discussion purposes, assume that a five (5) gpm leak develops in the RCS. With 40 gpm letdown, four (4) gpm control bleedoff flow, and five (5) gpm leakage, the total outflow from the RCS is 49 gpm. Since only one charging pump is operating, level in the pressurizer will start to decrease. When the PID controller senses that level is below setpoint, the letdown flow control valves will decrease letdown flow. Charging will return level to setpoint.

6.2.5 Summary

The PLCS maintains the water inventory of the RCS by varying both letdown and charging flow. In addition, the system will provide low and high level signals to the pressurizer heaters.

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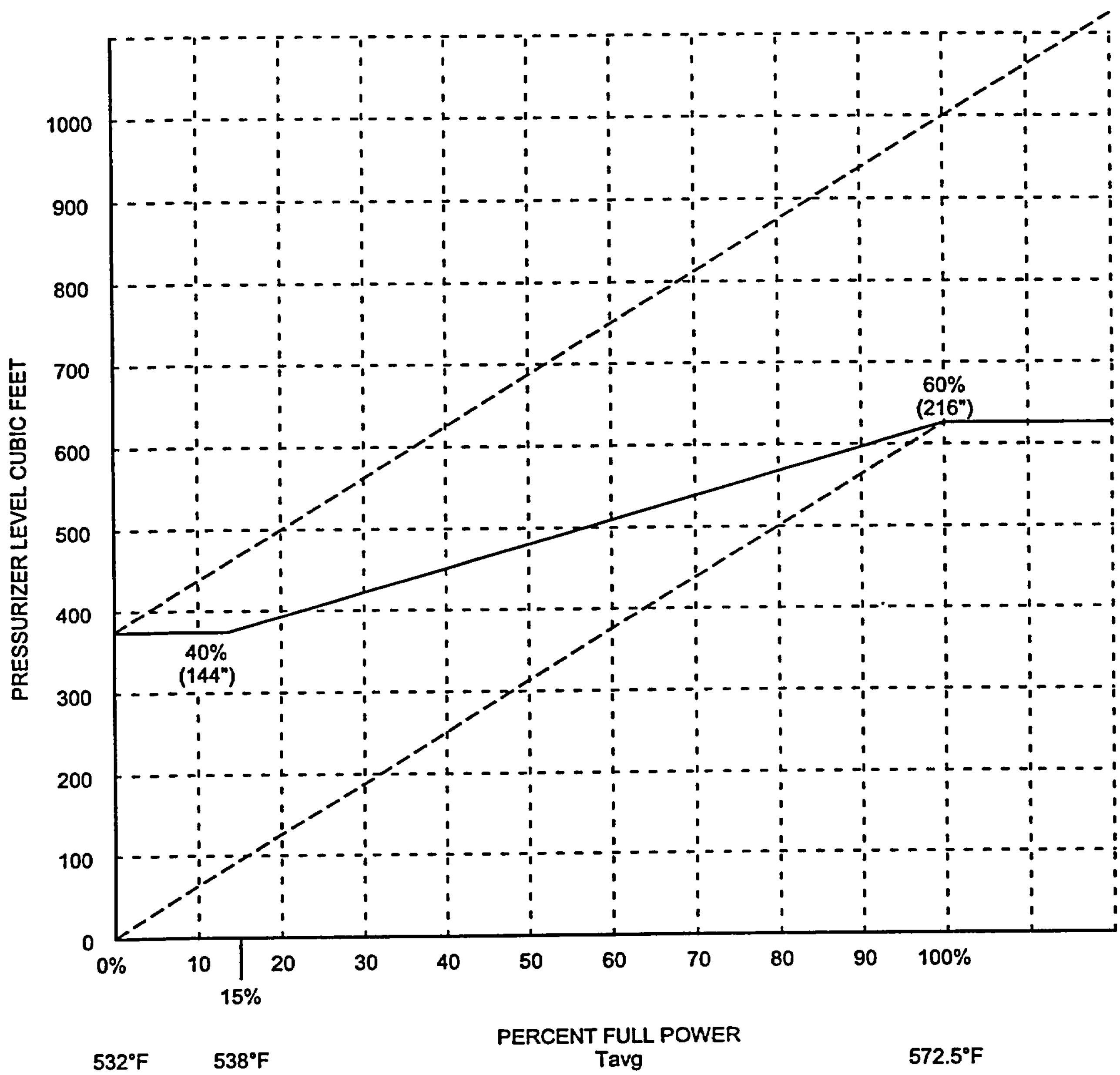

Figure 6.2-1 Pressurizer Level Program

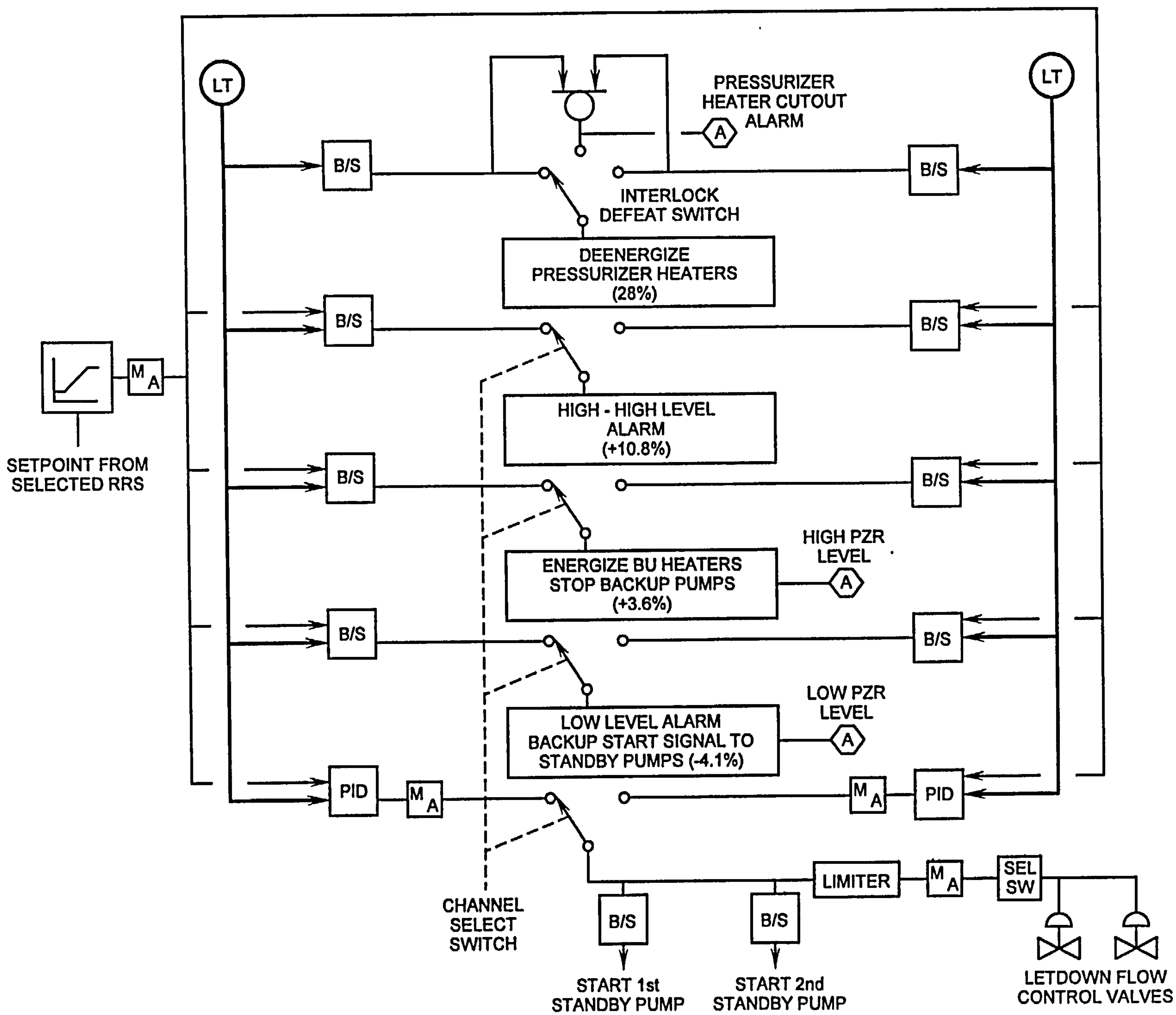

Figure 6.2-2 Pressurizer Level Control System

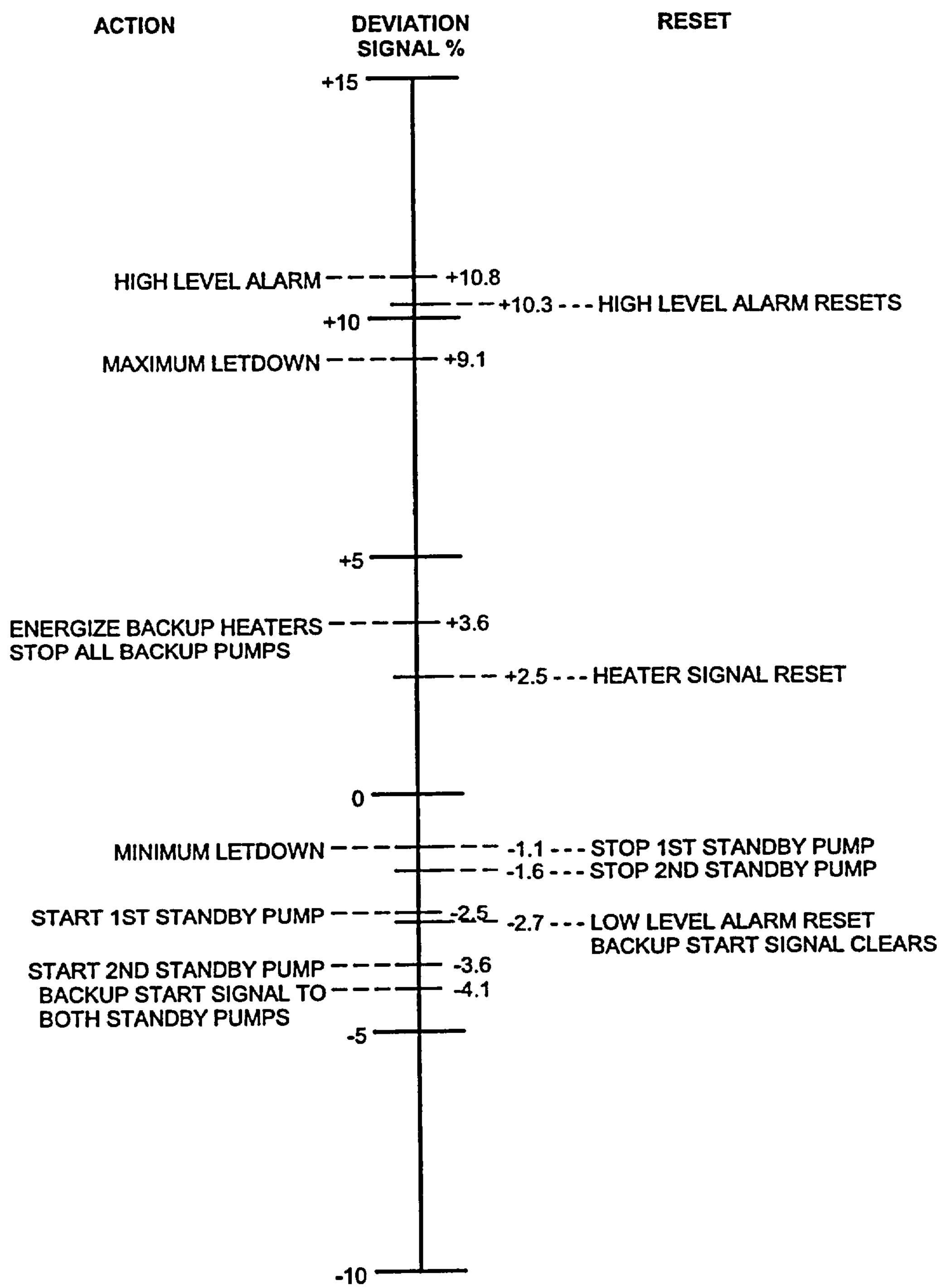

Figure 6.2-3 Control System Actions

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Chapter 7

FEEDWATER CONTROL SYSTEM

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7.0 FEEDWATER CONTROL SYSTEM

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7.0 FEEDWATER CONTROL SYSTEM

Learning Objectives:

1. State the function of the feedwater control system (FWCS).
2. List the inputs used to control steam generator water level and describe how each input is used.
3. List the override signal associated with the FWCS.
4. Explain the two modes of automatic control for the FWCS.
5. Explain the difference between actual and indicated steam generator level following a plant cooldown.
6. Describe the effect initial power level has on the magnitude of shrink and swell.

7.1 Introduction

Each steam generator is equipped with independent three (3) element and single (1) element controllers. The elements used are steam flow, feed flow, and level. These elements will be used to control feedwater flow to each steam generator to maintain proper steam generator level during normal plant operation. The FWCS will automatically control steam generator level above 15% power using the three (3) element mode of control. During startups and shutdowns, when below 15% power, a single element (level only) control is selected, and the feed water bypass valves will be controlled to maintain steam generator level.

The FWCS is designed to perform the following functions:

1. Automatically maintain steam generator water level at the designed normal water level using a three element control system above 15% power and a single element control system below 15% power,
2. Provide reduced feedwater flow after a turbine trip by shutting the main feedwater regulating valve (FRV) and positioning the bypass FRV to supply five percent (5%) of main feedwater flow to each steam generator and
3. Allow the operator to manually control the main and bypass FRV's to control feedwater flow to each steam generator.

The main feedwater line to each steam generator is provided with a feed water regulating valve and a bypass valve. The bypass valve may be used to manually control feed water flow at no load or low load operations. An additional control function of the FWCS is to adjust the speed of the turbine driven main feed pumps. This signal is varied between minimum and maximum as a function of the differential pressure (ΔP) across the FRV.

7.2 FWCS Inputs

7.2.1 Steam Generator Level

Two (2) level detectors per steam generator measure the ΔP between the upper and lower taps in the downcomer area of the steam generator. One is used for high/low steam generator level alarms and for the operation of the feedwater regulating bypass valve (through the single element controller). The remaining transmitter is used for level indication and control of the FRV (through the three element controller). Steam generator alarms, penetrations, and operating limits referenced to the low level tap (0% indicating) are listed in Table 7-1.

Table 7-1 Steam Generator Level	
High level tap	100%
High level turbine trip	92.5%
High level alarm	81%
Bottom of steam separators	78%
Normal level	65%
Surface blowdown ring	61%
Low level alarm	51%
Low level pre-trip	47%
Feed ring	39%
Low level reactor trip	37%

Differential pressure (D/P) cells are used to produce a signal proportional to steam generator downcomer level by measuring the difference in pressure between a reference leg and a variable leg. The reference leg (high level tap) has a constant level maintained by a condensate pot. The condensate pot and reference leg are unlagged and located external to the steam generator. Steam (525°F) is condensed in the condensate pot where the ambient temperature is relatively low (120°F). The variable leg (low level tap) has a variable level due to the changing downcomer level. Electronic force balance transmitters convert the ΔP to a 4-20 ma current signal. The maximum signal output occurs at maximum level (which corresponds to a minimum ΔP). The detectors are narrow range instruments measuring 183 inches of level in the normal operating range. The level indicators display level as zero (0) to one-hundred percent (100%).

Since density compensation is not incorporated in the level detection circuitry, manual level correction is required for reduced steam generator pressure (temperature). Transmitters are calibrated for a generator pressure of 850 psia. Since the reference leg is external, its temperature is constant (120°F ambient). As steam generator temperature is reduced (during a cooldown), the reference leg density is constant, but the density of the steam generator water increases. If indicated level is maintained constant at 65% then the actual level will decrease as the steam generator temperature is reduced. At 850 psia, indicated level equals actual level (65%). At 14.7 psia, indicated level equals 65%, but actual level equals 47.5%.

7.2.2 Steam Flow

An elbow tap (located inside containment) at the outlet of each steam generator measures steam flow. The steam flow is forced to the outer radius of the elbow causing a measurable ΔP to be developed. An electronic force balance D/P transmitter produces a 4-20 ma electrical signal that's proportional to the ΔP. The signal is biased to always have a minimum output of approximately 10% due to the inaccuracies of sensing such a small ΔP. The steam flow system is calibrated for operation at 850 psia.

7.2.3 Feed Flow

A venturi flow nozzle, downstream of the FRV, is used to sense main feedwater flow. The venturi nozzle has a restriction which causes a measurable ΔP proportional to the flow rate. An electronic force balance transmitter and square root extractor is used for producing the feed flow signal. As with steam flow, the feed flow signal output is biased at 10% due to the existence of similar inaccuracies at small ΔP signals. Like the steam flow system, the feed flow system is calibrated for its normal operating range

7.3 FWCS Normal Operations (Figure 7-1)

7.3.1 Below 15% Power

During plant startup (< 5% power) the

auxiliary feedwater system may be used to feed the steam generators until a main feedwater pump is operating. Since the auxiliary feed pump turbine exhausts to the atmosphere and there is no automatic level control associated with this system, this is not a desirable method for level control. A main feedwater pump is normally placed in service between three (3) and five percent (5%) power to minimize the use of the auxiliary feedwater system.

With power less than 15%, steam generator level is controlled by a single element controller. Actual steam generator downcomer level is compared to a manually adjusted level setpoint signal (normally 65%). The deviation from setpoint (level error) is amplified by a proportional controller with the resulting signal used to adjust bypass FRV position such that the deviation is zero. The controller gain is set to allow a proportional band of 22% level (the bypass valve will be fully open when actual level is 22% below setpoint). Valve capacity is 15% of 100% feed water flow or 2150 gpm.

When controlling steam generator level with the bypass FRV, the manual isolation valves upstream of the main FRV are normally closed. Although the main FRV's are closed, feedwater leakage past them may exceed the rate of steam generation within the steam generator leading to high water levels.

7.3.2 Above 15% Power

When power is approximately 15%, level is controlled by a three (3) element controller. Feed water flow is compared with steam flow to determine the flow error. Actual steam generator level is compared with a level setpoint (65%) to determine the level error. The two error signals are combined to position the main FRV. The main FRV capacity is 14,310 gpm.

The lag circuits act to anticipate changes. The faster the input changes (with respect to time), the greater the magnitude of the output signal. For example, a level decrease of 10% in 20 seconds will produce a larger error signal than a level decrease of 10% in 40 seconds. The proportional plus reset (integral) controller can have an output when no input deviation exists. The reset action allows actual level to equal the level setpoint. This action is necessary since the main FRV must be continuously opened as power increases, hence the total valve signal must increase even though feed flow equals steam flow and steam generator level equals setpoint.

The gain of the flow error circuit is twice the gain of the level error circuit. This arrangement compensates for the effects of shrink and swell which occur during transients. The three (3) element system is unstable at low power levels, since feed and steam flow signals are inaccurate at low flow conditions, and small changes in valve position result in large flow changes. To minimize this unstable characteristic, the main FRV controller is usually operated in manual with the FRV closed during low steaming conditions.

In addition to bypass and FRV positioning, the FWCS adjusts turbine feedwater pump speed. Consider the example of the FWCS sensing an increase in steam generator level, which will reduce the opening on the main feed water valves, due to level error. The reduced opening restricts flow and causes an increase in differential pressure across the FRV for the same feedwater turbine speed. The differential pressure controller senses the increased ΔP, transmits a signal to the speed changer calling for a reduction in turbine speed. Reducing the turbine speed decreases pump discharge pressure which reduces the FRV ΔP. The end result will be a new turbine speed and valve position, for the same ΔP, to maintain the new steam generator condition.

7.4 FWCS Transient Operation

7.4.1 Step Change in Power

Assume the plant is operating at 50% power and steam generator level is at setpoint with steam flow and feed flow matched. A negative step change (-10%) in steam flow results in a rapid water level decrease (shrink). Initially the control system receives two opposing signals. The decreasing water level (shrink) demands an opening of the main FRV to restore level to setpoint (65%). The large flow error requires the main FRV to be shut so that feedwater flow will equal steam flow. During the initial part of the transient, the flow error signal is dominant due to the larger gain of the flow error circuit. If the valves were allowed to open on the transient as a result of level error (due to shrink), then a large flow error would exist (feed flow > steam flow) and a large overshoot in level would occur.

As the transient progresses, the flow error is reduced and the water level error becomes dominant during the remaining part of the transient in order to restore level to setpoint. The overshoot in level is characteristic of the response of any complex controller. The gains, reset time, and lag times are adjusted such that these overshoots and oscillations are minimized. At the end of the transient new steady-state conditions are reached with feedwater flow matching steam flow and the steam generator water level at setpoint.

The response of the three (3) element control system to step changes in turbine load becomes more sensitive and results in larger overshoots as the initial power level is reduced. The magnitude of shrink and swell effects increases as initial power level is reduced. A 10% step increase in steam flow starting from 20% power results in a 50% increase in heat flux transferred from primary to secondary. The same step change from an initial power of 90% results in a heat flux increase of only 11%. Since the volume occupied by steam bubbles is proportional to the change in heat flux, the swell will be greater at the lower power level.

7.4.2 Turbine Trip

In order to prevent overcooling following a turbine trip, (remember that the reactor trips if power is greater than 15%) feedwater flow is automatically ramped down to five percent (5%) of its 100% value. This is accomplished by closing the main FRV regardless of its mode of control and positioning the bypass valves to 33% open. This bypass valve position corresponds to five percent (5%) feedwater flow. Manual push buttons are installed to allow the operator to remove the ramp down signal.

A turbine trip results in a ramp down in feed water flow to five percent (5%) of full flow within 60 seconds. The electrical signal to the FRV is grounded resulting in the valve shutting within 60 seconds regardless of its mode (manual or auto). A trip override is provided to restore manual control to the bypass valve (FRV remains closed). The feed water bypass valve receives a signal of 33% of total such that it provides five percent (5% of rated feed flow. A ramp down will provide a better regulation of cooldown after a trip.

7.4.3 Level Transmitter Failures

A leak or rupture in the reference leg will reduce pressure on the high side of the D/P cell. A minimum ΔP will be sensed by the D/P cell which gives a high level output. A leak or rupture in the diaphragm which separates high pressure and low pressure fluids will cause a minimum ΔP and give a high level output.

Each steam generator has two (2) level transmitters that are used for control by the FWCS. The two transmitters are connected to the

FWCS via a selector switch. During normal operation, the output of one transmitter is sent to the three (3) element control system and a level recorder. The output of the second transmitter is sent to level alarms, level indicators, and the single (1) element control system. During a transmitter failure, the selector switch is used to select the remaining operating transmitter and allow it to drive both the three (3) element and the single (1) element control systems and therefore no control functions will be permanently lost.

Failure of the level transmitter associated with the bypass FRV will give high/low level alarms and a high/low indicated level on the main control board regardless of power level or mode of control. The level recorder will continue to indicate normal level. If power is below 15% and level is being maintained automatically, then the bypass FRV will fully open or fully shut. In either case, the operator should put the controller in manual and bring level back to setpoint. The problem can then be diagnosed and the non-failed level transmitter selected. If power is above 15%, there will be no effect on feedwater control. The level transmitter should still be repositioned since this action could be forgotten after a trip or shutdown.

Failure of the level transmitter associated with the main FRV will give high/low indications on the level recorders. The high/low level alarms would not come in until actual level, as sensed by the other transmitter, reached the alarm setpoint. Additionally, the level indicators would indicate normally. If power is above 15% and FRV control is in automatic when the level transmitter fails low, the FRV would receive a signal to fully open. This would cause a feed flow mismatch which would over feed the steam generators causing actual level to increase. This condition would continue until the operator takes corrective action. The immediate action would be to shift the control station to manual and restore steam generator level to setpoint. If left unchecked, a high steam generator level (92.5%) will be exceeded, causing a turbine trip, and a reactor trip will result.

7.5 Summary

The FWCS functions to control steam generator level during plant startups, normal operation, and plant shutdowns. Two different control schemes are employed. When the plant is operating at power levels less than 15%, a single (1) element (steam generator level) control is used. When the plant is operating at power levels greater than 15%, a three (3) element control system (steam flow, feed flow, and steam generator level) is used.

The FWCS provides an override feature when the turbine is tripped. The override feature consists of closing the FRV and positioning the bypass valve to thirty three percent (33%) open.

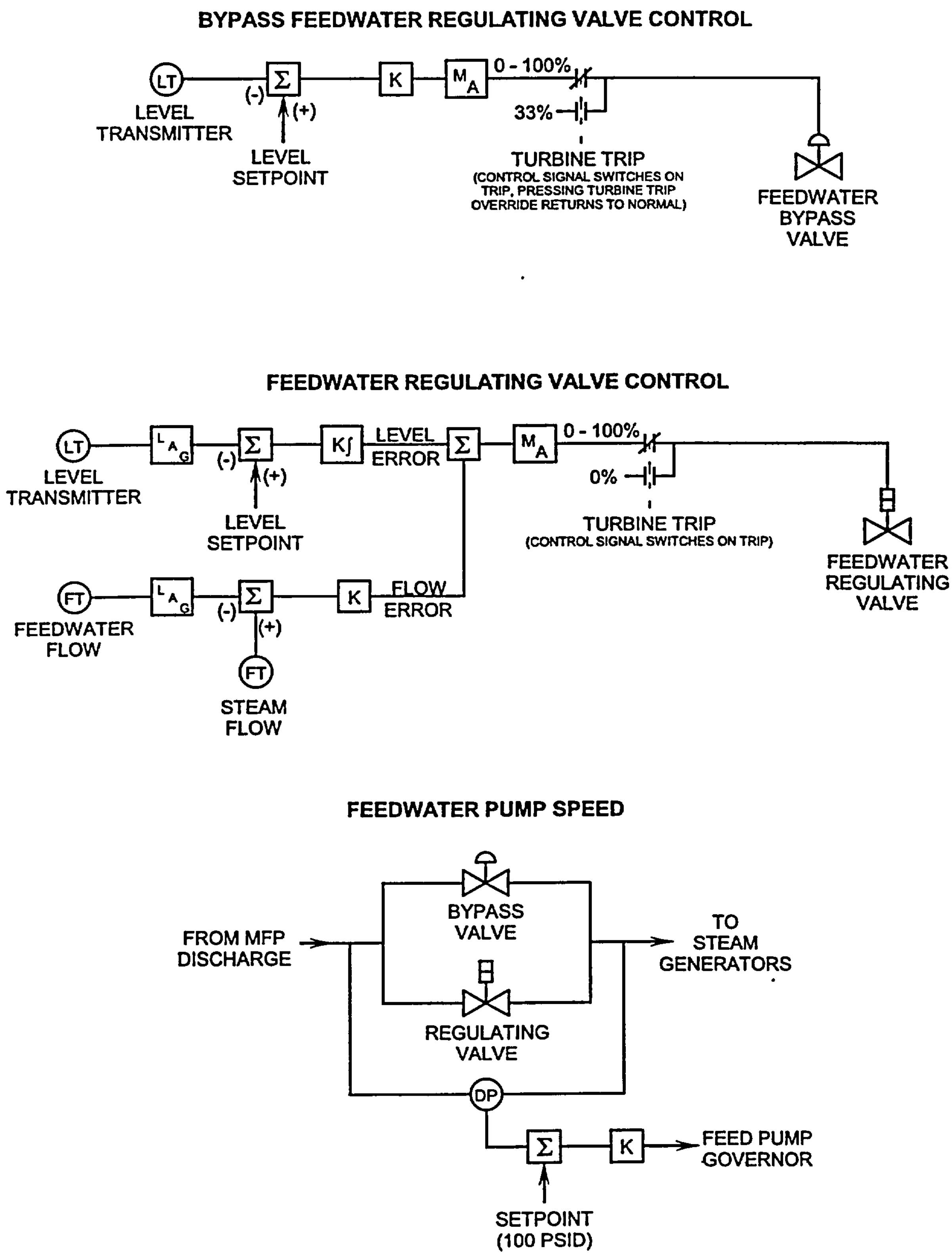

Figure 7-1 Feedwater Control System

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Chapter 8

STEAM DUMP AND BYPASS CONTOL SYSTEM

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8.0 STEAM DUMP AND BYPASS CONTROL SYSTEM (SDBCS)

Learning Objectives:

1. List the purposes of the steam dump and bypass control system (SDBCS).

2. Briefly describe how each purpose is accomplished.

3. List the input signals to the SDBCS.

4. Describe how over-pressurization of the condenser is prevented.

8.1 Introduction

The SDBCS exists to remove excess energy from the reactor coolant system (RCS) by dumping steam to the atmosphere and/or bypassing main steam flow around the turbine directly to the condenser. Operational conditions that can result in excessive RCS energy are:

1. Load rejection or turbine trip,

2. Reactor trip,

3. Reactor start-up or

4. Plant cooldown.

A load rejection is a complete or partial loss of electrical power generation. It is desirable to immediately reload the turbine generator following a load rejection in order to restore the unit output to normal. Since electrical generation is proportional to turbine steam flow, a load rejection results in excessive RCS energy. If this excessive energy is not removed, a high pressurizer pressure trip will result and the ability to immediately reload the turbine will be lost.

When the reactor trips, the turbine also trips. The tripping of the turbine drops the heat removal from the RCS to zero (0). If the reactor trips from 100% power steam generator pressure approaches a value that corresponds to saturation pressure for 572°F. This pressure is in excess of 1200 psia and would lift all of the main steam safety valves. Therefore, the SDBCS is designed to remove this excessive energy and restore RCS temperature to the no load value of 532°F following a reactor trip.

Thus far, only upset conditions that cause excessive RCS energy have been discussed. However, during a reactor start-up, reactor power is increased while turbine power (normal heat removal) remains at a value of zero. This increase in reactor power causes excessive RCS energy that is removed by the SDBCS. Excessive RCS energy during a reactor startup is required for two (2) reasons. First, as the SDBCS removes energy, a constant steam flow (for a given power level) is established. In order to maintain steam generator level, an increase in feedwater flow is required. If the power escalation is performed in a slow orderly fashion, manual control of feed water is easier. Also, the escalation of reactor power to a pre-determined value (8-10%) provides sufficient energy for turbine warmup, roll to synchronous speed, and initial loading. As the turbine is loaded, the SDBCS valves will close and energy removal from the RCS will remain constant until turbine load exceeds reactor power.

The final function of the system involves the removal of excess energy during a plant cooldown. During this evolution, RCS temperature is reduced to the shutdown cooling initiation point by dumping steam to the condenser or to the atmosphere.

8.2 SDBCS Components

In order to accomplish the functions previously discussed, the SDBCS controls six (6) valves that are divided into two (2) groups. The first group is the bypass group consisting of four (4) valves. These valves bypass main steam flow around the turbine. The bypass valves have a total capacity of 40% of rated steam flow, and are connected to the main steam header downstream of the main steam isolation valves. The second group of valves are called the dump valves and release steam directly to the atmosphere. The two (2) dump valves have a total capacity of 5% of rated steam flow, and are connected to the main steam headers upstream of the main steam safety valves. Each of the dump valves has an associated isolation valve located between the dump valve and the main steam header.

The total steam flow handling capacity allows the SDBCS to control secondary steam pressure without requiring operation of the main steam safety valves. The bypass valve operation is sequenced to prevent abrupt changes in RCS heat removal. In the event of a loss of condenser vacuum, the turbine bypass valves close automatically. The atmospheric dump valves are designed to remove reactor decay heat when the condenser is not available. The SDBCS valves are designed to withstand a maximum steam pressure of 1000 psig at 580°F.

8.3 SDBCS Operations (Figure 8-1)

8.3.1 Load Rejection

Assume the unit is operating at full electric output and the control element assemblies (CEAs) are in the automatic sequential mode of operation. For some unknown reason, electrical load is reduced by 40%. When the step change in electrical load occurs, the turbine control valves will close to prevent a turbine overspeed condition. As the turbine control valves close, steam flow decreases rapidly which leads to an increase in steam pressure. The bypass valves will be sequentially opened as steam pressure increases (depending on the amount of pressure increase). When steam pressure exceeds 895 psia, the bypass valves begin to open. The bypass valve pressure controller generates an output signal proportional to secondary pressure over the range of 895 to 905 psia (for a setpoint of 900 psia). Meanwhile, the CEAs are being inserted by the reactor regulating system (RRS) due to the mismatch between reactor and turbine power. As the CEAs add negative reactivity, reactor power is reduced. With the SDBCS valves open, the reduction in reactor power causes a reduction in steam pressure. As steam pressure decreases, the pressure error gets smaller and the bypass valves start to close. These actions will continue until the RRS restores Tavg to the proper value for the corresponding power (turbine load).

8.3.2 Turbine Trip

The steam dump controller generates a suppressed range signal, Tavg error, which is proportional to actual Tavg minus 532°F. Upon receipt of a turbine trip, the dump controller signal opens the atmospheric steam dump valves, and a simultaneous signal is applied to the turbine bypass auctioneering circuit to open the bypass valves. The position of the SDBCS valves is proportional to the signals applied to them, which provides a controlled discharge of excess pressure. The magnitude of the programmed Tavg error signal is directly proportional to the amount of heat energy stored in the reactor coolant.

When the reactor is operating at approximately 8% power (Tavg ~535°F), the programmed Tavg signal magnitude is minimum. At 63% power (Tavg ~ 557°F) the programmed Tavg error signal magnitude is maximum. When the turbine trips while reactor power is between 8% and 63%, the programmed Tavg error signal is applied through the main control circuits to the current to pneumatic signal (I/P) converters, resulting in a similar response of the system with the CEA interface as discussed in section 8.3.1.

When the main turbine trips while the reactor is operating above 63% power, the RRS supplies a quick open (QO) signal to energize the solenoid dump valves. When the solenoid valves are energized, the pneumatic signals from the current to pneumatic converters are isolated and a higher air pressure from the instrument air system is applied to the dump valve actuators through the solenoid valves. This causes the dump valves to rapidly move to their fully open position.

The release of secondary steam flow to the atmosphere through the steam dump valves following a reactor trip causes Tavg to decrease. Once Tavg drops below approximately 548°F, the solenoid valves are deenergized (QO signal cleared), allowing the programmed Tavg error signal to assume control of dump valve position. The programmed Tavg error signal continues to vary directly with Tavg. As Tavg decreases toward 535°F, the steam dump valves move proportionately toward their shut position. Once Tavg drops below 535°F, the dump valves are fully shut. Should Tavg begin to increase above 535°F, the dump valve controls hold the valves shut until Tavg reaches 540°F, at which time the dump valves are reopened by an amount corresponding to the strength of the programmed Tavg error signal.

The programmed Tavg error signal continues to position the valves as previously described. The automatic positioning of the steam dump valves is referred to as modulating the valves. When the controller is in manual, the positioning of the dump valves is controlled by manually adjusting the amount of current applied to the converters.

8.3.3 Reactor Trip

If a load rejection occurs which is in excess of the capacity of the SDBCS, the resulting temperature and pressure transient will cause a reactor trip. When the reactor trips, a turbine trip signal is generated, closing all the turbine control valves. If Tavg is above 557°F with a turbine trip present, a quick open signal is generated.

The actuation of the SDBCS valves following a reactor trip causes Tavg to decrease. Once Tavg drops below 548°F, the solenoid valves are de-energized (QO signal cleared), allowing the programmed Tavg error signal to assume control for the position of the SDBCS valves. The Tavg error signal continues to vary directly with Tavg. As Tavg decreases toward 535°F, the steam dump valves are modulated toward the closed position. Once Tavg decreases below 535°F, the steam dump valves are fully closed. Should Tavg begin to increase, and again go above 535°F, the steam dump controls hold the dump valves closed until Tavg reaches 540°F. This Five degree (5°F) deadband allows the bypass valves (if available) to control the heat removal based on pressure, which minimizes the amount of secondary inventory lost to the atmosphere. If Tavg reaches 540°F, the steam dump controls reopen the dump valves by an amount corresponding to the strength of the Tavg error signal.

The automatic positioning of the valves is referred to as modulating the valves. At the end of the transient, steam pressure should equal about 900 psia which corresponds to an average RCS temperature of 532°F.

8.3.4 Startup

Before the reactor can be taken critical, the RCS is heated up to no load temperature by the operation of the reactor coolant pumps. As the pumps add heat energy to the steam generators, steam pressure increases. When steam pressure tries to exceed the SDBCS setpoint of 900 psia, an error signal will be generated. The error signal will cause the bypass valves to open and will maintain steam pressure at 900 psia. As reactor power is escalated, Tavg increases. The increase in temperature tries to raise steam pressure, however, the error signal from the pressure controller increases. The increase in the error signal will cause the bypass valves to open further and steam pressure will remain at 900 psia.

As the turbine is loaded, steam flow increases and steam pressure tries to decrease. The decrease in steam pressure will be sensed by the SDBCS and the pressure error signal to the bypass valves will decrease. The decrease will continue until the SDBCS valves are fully closed and all the steam flow is being directed through the turbine. In the event of a loss of condenser vacuum, the turbine bypass valves close automatically and the atmospheric steam dump valves open, exhausting steam to the atmosphere and maintaining temperature between 535°F and 540°F.

8.3.5 Plant Cooldown

When the reactor is shutdown; and being maintained in a hot shutdown condition, the steam dump and bypass controllers remain at their normal setpoints. In order to decrease RCS temperature, steam from the steam generators is dumped to the condenser. The operator takes manual control of the steam pressure controller and increases the output of the controller. The output is routed to the I/P converter and the bypass valve(s) will achieve the desired position. Remember that the rate of RCS cooldown is limited by plant technical specifications. RCS temperature is reduced by manual operation of the SDBCS valves until the proper temperature is obtained for shutdown cooling system operations.

8.4 Summary

The purpose of the SDBCS is to remove excess energy from the RCS by dumping steam to the atmosphere and/or bypassing steam to the main condenser. Excess energy can be caused during load rejections, turbine trips, reactor trips, reactor start-up or plant cooldowns.

The system consists of six (6) valves. Four (4) valves are bypass valves and have a total capacity of 40% of rated steam flow. Two (2) valves are dump valves and have a total capacity of 5% of rated steam flow.

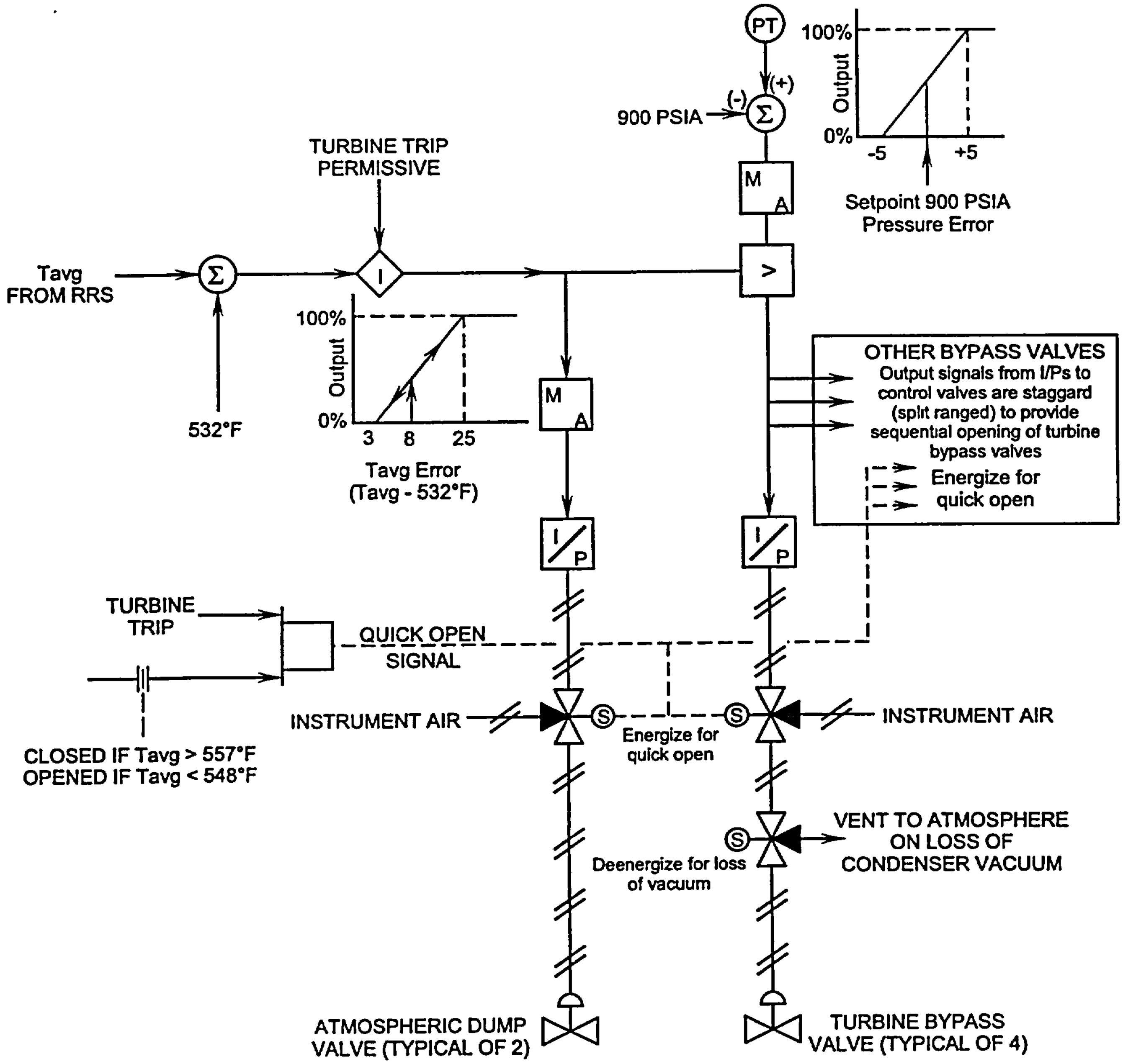

Figure 8-1 Steam Dump and Bypass Control System

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Chapter 9

CORE MONITORING SYSTEMS

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9.1 EXCORE NEUTRON MONITORING SYSTEM

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9.1 EXCORE NEUTRON MONITORING SYSTEM

Learning Objectives:

1. List the purposes of the excore nuclear instrumentation system.

2. Explain the basic operation of the following excore neutron detectors and state the detector type used in each range of the excore neutron monitoring system:

   a. B^{10} proportional counter
   b. Fission chamber
   c. Uncompensated Ion chamber

3. Describe the following excore nuclear instrumentation system interfaces and interlocks:

   a. Wide range logarithmic channel high voltage interlock
   b. Wide range logarithmic channel and linear power range safety channel overlap.
   c. Wide range channel and linear power range safety channel reactor protection system (RPS) inputs.
   d. Non-safety related linear power range safety channel interfaces.

4. Explain how the excore nuclear instrumentation is capable of detecting both radial and axial power distributions.

5. Explain how the linear power range safety channel is calibrated to indicate reactor thermal power.

6. List the power range linear control channel outputs.

9.1.1 Introduction

The purposes of the excore neutron monitoring system are:

1. To monitor neutron flux from the source level to 200% of full power.

2. To provide indication in the control room of neutron power and the rate of change of neutron power.

3. To provide power level signals to the reactor regulating system (RRS).

4. To provide power level signals and the rate of change of power signals to the reactor protection system (RPS).

5. To provide information on axial power distribution to the control room and the RPS.

The excore neutron monitoring system senses leakage neutron levels from $10^{-9}\%$ to 200% power. In order to accurately cover this enormous region, the excore system is divided into the wide range logarithmic and linear power range safety channels. In addition, a non-safety related power range linear control channel is provided. The wide range logarithmic channel provides indication from $10^{-9}\%$ to 200% power and also provides start-up rate indication and inputs to the RPS. The linear power range safety channels provide indication of power from one percent (1%) to 200% power and supplies trip signals to the RPS. Finally the power range linear control channel provides indication of reactor power from one percent (1%) to 125% power and supplies an input to the reactor regulating system (RRS).

The wide range logarithmic channels and the linear power range safety channels are successively overlapped to prevent a loss of indication when one range is operating at the high end of its scale, and the next range is operating at the low end of its scale. The three (3) excore channels and their overlapping regions of indication are shown in Figure 9.1-1. Redundant safety channels are installed to assure protection and indication in the event of a single channel failure.

9.1.2 Detector Theory

Radiation can be placed into three basic categories:

1. Charged particles (alpha, beta, protons),

2. Uncharged particles (neutrons) and

3. Electromagnetic radiation (gamma rays).

For most radiation detection systems charged particles are collected within a detector. These particles are either counted or measured to provide a usable output signal. Since only charged particles can be detected, neutrons must interact within the medium of the detector to produce charged particles.

A gas detector curve (Figure 9.1-2) shows how ion pairs collected varies with the applied voltage. A charged particle ionizes the gas within the detector which produces ion pairs. The positive charges are drawn to the negative voltage electrode while the negative charges migrate to the positive electrode.

In the recombination region (region I), the charge current will increase as the applied voltage is increased because less ion pairs are capable of recombining with higher voltage.

In the ionization chamber region (region II), the ions move too fast for recombination to occur. The charge current is constant because all ion pairs produced are collected. The gas amplification factor in this region is unity. The power range linear safety channel and linear control channel uncompensated ion chambers operate in this region. Also, the wide range logarithmic channel fission chamber operates in this region.

A further increase of applied voltage will cause a proportional increase of ion pairs collected in the proportional counter region (region III). The proportional increase is a result of the original ion pairs causing secondary ionization or an avalanche effect. The gas amplification factor can be as high as 10^6 in this region. The B^{10} detector used in the wide range logarithmic channel operates in the proportional counter region.

Eventually the gas amplification will become space charge limited at the electrodes with an observed fall off of the proportional relationship between ion pairs and applied voltage. The fall off occurs in the limited proportional region (region IV). Region IV is seldom used in radiation detection.

The Geiger-Muller region (region V) is where the detector current is independent of the primary ion pair and incident radiation energy level. The detector completely discharges for any ion pair formed. Some portable gamma detectors operate in region V.

9.1.3. Detector Locations

The excore neutron detectors are located in wells external to the reactor vessel. The location of the detectors in, or next to, the biological shield, is illustrated in Figure 9.1-3. The arrangement provides radial and axial symmetry about the core. It should be noted that a wide range logarithmic and a linear power range safety channel is located adjacent to each core quadrant. The wide range logarithmic channel detectors are at or near the core center line. One of the linear power range safety channel detectors extends axially along the lower half of the core while the other, which is located directly above it, monitors flux from the upper half of the core.

9.1.4 Wide Range Logarithmic Channel Basic Description

The four (4) wide range logarithmic channels provide indication of power level from the source levels (0.1 counts per second) to 200% power. However, only the range from one-tenth (0.1) cps to 150% power is displayed in the control room. Two (2) different types of detectors, two (2) circuits, and two (2) indicating ranges are required to cover this large range of neutron flux. Each of the channels is supplied with inputs from B^{10} proportional counters and a fission chamber. The input signal is processed by a pulse counting circuit and a campbelling circuit. Finally, the indication from the wide range logarithmic channel is displayed in counts per second (cps) and percent power.

9.1.5 Wide Range Logarithmic Detectors

In the source level and low power region, the wide range logarithmic channel utilizes a B^{10} proportional detector to enhance the sensitivity of the channel. The B^{10} detector is more sensitive than the fission chamber in this area of operation. The B^{10} detector (Figure 9.1-4) consists of a central anode surrounded by an aluminum cylinder. The inside of the aluminum cylinder is coated with B^{10}. When a neutron enters the detector, it reacts with the boron producing an alpha particle and a lithium nucleus. These particles are created with a kinetic energy of between 2.3 and 2.78 MeV. As these highly energetic particles travel through the gas contained within the detector assembly, many ion pairs are created. The positive charges are drawn to the negatively charged cylinder, while the negative charges are collected by the central anode. The resultant output of the detector is an electrical pulse. Gamma rays also react with the detector's boron lining. Gamma rays react with matter through Compton's scattering, the photoelectric effect, and pair production. Each of these mechanisms produces an electron, therefore, the charge produced inside of the detector by secondary ionization is small.

Each channel contains two (2) B^{10} assemblies with four (4) detectors in each assembly. The four (4) detectors are connected in parallel to increase channel sensitivity. The output from the proportional counters is used in the extended range of indication. The extended range corresponds to flux levels from 10^{-9}% power to 10^{-4}% power. Extended range indicating lamps, located on the RPS cabinets, are energized when power level is in this range. High voltage to the B^{10} detectors is removed when power reaches 1000 counts per second (~10^{-7}% power). The removal of high voltage prevents damaging the detector due to the large number of ionizations occurring.

In addition to the B^{10} proportional detector input, each wide range logarithmic channel also receives an input from a fission chamber. The fission chamber (Figure 9.1-5) is internally coated with uranium oxide that has been enriched to greater than 90% U^{235}. When a neutron enters the detector, a fission reaction occurs. This reaction results in two highly charged fission fragments that create secondary ionization in the argon-nitrogen fill gas and a charge is generated. The output of the fission chamber is used in the pulse counting circuit and the Campbelling circuit.

9.1.6 Wide Range Logarithmic Power Circuitry (Figure 9.1-6)

9.1.6.1 Charge Amplifier and Preamplifier

The outputs of each proportional counter assembly and the fission chamber are fed individually to a charge amplifier and then to a preamplifier located in the containment building. A charge amplifier for each input signal is provided to minimize the effects of combined detector capacitance on the signal characteristics.

The pre-amplifier increases the signal to noise ratio of the detector outputs and transmits the signal to the RPS cabinets located in the control room. Provisions are made to insert a test signal to check pre-amplifier calibration and cable continuity.

9.1.6.2 Pulse Counting Circuitry

The log count rate circuitry consists of a discriminator, a log count rate amplifier, and receives its input from the preamplifier. The discriminator functions to remove gamma and noise from the input signal. Since the gamma pulse is approximately one-sixth (1/6) the size of the neutron pulse, elimination of the signal is accomplished by setting a minimum voltage level for processing. This minimum voltage level is greater than the voltage pulses due to gammas and noise; therefore, only the neutron signal passes to the log count rate amplifier.

In addition to supplying an input to the log count rate circuit, the discriminator also supplies an output to the audible count rate indication. The audible count rate circuitry may be supplied from any one of the four (4) wide range logarithmic channels and consists of two (2) speakers (one in the control room and the other in the containment building) and an audio amplifier. The audible count rate is proportional to the neutron flux being sensed by the detector and can be divided by a frequency select switch. Thus, the final audio tone varies with the count rate and the frequency division selected. The audible count rate circuitry is required to be in operation during refueling and may be used during reactor start-ups.

The log count rate amplifier converts the neutron pulses into a logarithmic signal. A logarithmic signal is required to allow accurate resolution of the wide range of neutron flux indication.

The output of the log count rate circuit is routed to an indicator and a summing amplifier. The indication provided by the output of the log count rate circuitry is calibrated in counts per second (cps) and has a range of one-tenth (0.1) to 10^4 cps. The indication is actually one-half (1/2) of a dual indicator that is shared with the Campbelling circuitry. The left hand side of the indication is calibrated in cps, and the right hand side is calibrated in % power with a range of 10^{-8} to 150%. Indicating lamps are energized to inform the operator of active circuitry.

9.1.6.3 Campbelling Circuitry

The campbelling circuitry consists of a bandpass amplifier, a root-mean-squared (rms) voltage amplifier, and a logarithmic amplifier.

The campbelling circuitry makes use of a condition called pulse pileup. The pulses are occurring at such a rate that they are piling on top of one another. If the output of the preamplifier is examined, one would see an erratic wave form with peaks and valleys. The higher the power level, the larger the amplitude of the peaks and valleys from the mean. If an rms voltmeter is used to measure the resulting ac voltage at the output of the preamplifier, it would be found that the ac voltage squared is proportional to power (Campbell's Theorem).

The bandpass amplifier is used to set the initial operating point of the campbelling circuit. This is accomplished by setting the frequency of the ac voltage that will be passed to the remainder of the circuitry. From the bandpass amplifier, the signal is routed to the rms amplifier where the signal becomes proportional to power. The logarithmic amplifier is used to convert the output of the rms amplifier to a logarithmic signal. A logarithmic signal is required to allow accurate resolution of the wide range of neutron flux indication. The campbelling circuit is used when flux levels are between 10^{-2}% and 150% power. The output of the campbelling circuit is combined with the output of the pulse counting circuit in the summing amplifier.

9.1.6.4 Summing Amplifier

The summing amplifier combines the output of the pulse counting circuit with the campbelling circuit and supplies a rate circuit and two (2) bistables. The output of the summing amplifier is also supplied to a selector switch that is used to select the desired wide range logarithmic signal for display on a control room recorder.

9.1.6.5 Circuit Summary

When the reactor is shutdown and the neutron flux is at the source level, the wide range logarithmic channel is receiving its input from the B^{10} proportional detectors, processing its input via the pulse counting circuitry, and displaying its output on the dual indicators. The dual indicators are indicating power level on the extended range (cps). A typical reading for this condition is 10 to 30 cps. The next evolution is to take the reactor critical by CEA withdrawal. As the critical approach is made, flux increases, and the fission chamber begins to contribute to the pulse counting circuit's display. At 1000 cps, the B^{10} detector high voltage is removed and the dual indicators are shifted to the % power display. At this point, the fission chamber is supplying the entire pulse counting circuit input. This mode of operation continues until power is escalated to 10^{-2}%. At 10^{-2}%, the pulse counting circuit begins to saturate, and the campbelling circuit will provide flux information, via the summing amplifier, to the remainder of the wide range logarithmic channel circuitry. The campbelling circuity functions to provide flux indication from 10^{-2} to 150% power.

9.1.6.6 Rate Amplifier

The rate amplifier differentiates the logarithmic power signal obtained from the summing amplifier to provide a rate of change of reactor power (startup rate) to indication and protection circuits. Startup rate indication with a meter range of -1 to +7 decades per minute (DPM) is provided on indicators in the control room and RPS cabinets.

A high startup rate reactor trip will be generated if the start-up rate exceeds 2.6 DPM and reactor power is between 10^{-4}% and 15%. A pre-trip and associated control element assembly withdrawal prohibit (CWP) is generated if start-up rate exceeds 1.5 DPM. Safety analysis does not take credit for the CWP; therefore, it is not safety related.

9.1.6.7 Bistables

Three (3) bistables, two of which receive inputs from the summing amplifier and one bistable receives its input from the pulse counting circuitry, are used in each wide range logarithmic channel. The function of each bistable is listed below:

The **Level One Bistable** deenergizes when reactor power is above 10^{-4}%. When the bistable de-energizes, the following occurs:

1. The reactor protection system (RPS) zero power mode bypass is removed. The zero power mode bypass inhibits the thermal margin low pressure (TMLP) and low RCS flow reactor trips.

2. The ΔT power block is cleared. If the ΔT

power block is in effect, the selection of ΔT power by the TMLP calculator is prevented.

3. The TMLP CWP is enabled.

The **Level Two Bistable** deenergizes when reactor power is above 10^{-4}%. When the bistable de-energizes, the startup rate trip is enabled.

The **Level Sense Bistable** deenergizes at 1000 cps. When the bistable deenergizes, high voltage is removed from the B^{10} proportional detectors and wide range logarithmic indication shifts from the cps mode to the percent power mode.

9.1.6.8 Calibration and Testing

All of the wide range logarithmic circuitry, with the exception of the detectors and preamplifier, is located in the RPS cabinets. The calibration and test circuitry is also located in the RPS and consists of an operate - test selector switch, a six (6) position selector switch, a test trip selector switch, and a rate calibrate switch.

The level circuitry is tested by selecting six (6) discrete signals with the six (6) position selector switch. The signal is generated by a crystal oscillator in the wide range logarithmic RPS drawer. The switch is selected to the desired position, a signal is injected by the oscillator circuitry, and the indication is monitored to determine if the circuitry responded correctly to the injection of the test signal.

In the operate position, the trip point of the startup rate bistables may be tested utilizing a signal through a separate trip test switch. The startup rate circuit is checked by taking the rate calibrate switch to calibrate and observing a +7DPM meter indication. Leaving the switch in the operate position and utilizing the trip test switch, a ramp signal is used to check the set points of the of the startup rate pre-trip and trip bistables.

9.1.7 Linear Power Range Safety Channels General Information

The four (4) linear power range safety channels are capable of measuring flux linearly over the range of 0% to 200% power. The detector assembly consists of two (2) uncompensated ion chambers for each channel. The upper and lower detectors have a total active length of 12 feet. The dc current signal from each detector is fed directly to the RPS drawer without pre-amplification. The RPS drawer contains two linear amplifiers, a power summer amplifier, a deviation comparator, a comparator averager, subchannel comparators, and two (2) bistables.

9.1.8 Uncompensated Ion Chamber

The uncompensated ion chamber, Figure 9.1-7, is boron lined and detects neutrons by (n,a) reaction with $_5B^{10}$. Gamma rays produce a signal through the three (3) gamma ray/matter interactions. Gamma compensation is not required in the power range because the neutron signal is much larger than the gamma signal, and the gamma signal is proportional to power in the power range. As mentioned earlier, each of the four (4) channels use two (2) uncompensated ion chamber detectors. These two (2) detectors are positioned so that one (1) detector senses neutron flux from the bottom half of the core, and the other detector senses neutrons from the top half of the core. Since one detector is located on the top of the other, the linear power range safety channel circuitry can provide an indication of axial flux distribution as well as total power. Radial flux distribution can be determined by comparing the output of the four linear power range safety channels.

9.1.9 Linear Power Range Safety Channel Circuitry (Figure 9.1-8)

9.1.9.1 Linear Amplifiers

Each of the detectors associated with the linear power range safety channel supplies a linear amplifier. The linear amplifier increases the magnitude of the detector signal. Local meters monitor the output of the linear amplifiers and are calibrated to read zero (0) to 200% of the individual detector output. At 100% power, both meters will read 100%, assuming that a symmetrical axial flux distribution exists. In addition to supplying local power indication, the output of the linear amplifiers is routed to:

1. The power summer (The average of the lower detector output and the upper detector output),

2. The signal deviation comparator (lower detector output - upper detector output) and

3. The subchannel comparators.

9.1.9.2 Power Summer

The power summer accepts the output signals from the two linear amplifiers, sums the signals, divides the sum by two, and provides an output to:

1. TMLP reactor trip calculator,

2. Local power density (LPD) calculator,

3. Level 1 bistable (> 15%),

4. Rod drop bistable and

5. The comparator averager.

The summing amplifier is periodically calibrated by performing a secondary heat balance. This heat balance measures the power deposited in the steam generators by the reactor coolant system. The calculation involves determining the difference in the enthalpy (h) of the steam generator feedwater and the enthalpy of the steam generator exit steam. Multiplying this Δh by the mass flow rate converts the steam generator energy to steam generator power. Once actual power is known, the gain of the summing amplifier is adjusted to reflect actual power.

The output of the power summer is compared with ΔT power in the TMLP calculator and the higher of the two (2) power signals is used in the calculation of the TMLP trip set point and in the variable over power trip (VOPT).

The output of the power summer is also supplied to the linear power density (LPD) calculator. The LPD calculator uses the signal in the calculation of axial shape index (ASI) and in the determination of the LPD trip set point.

There are two bistables that are controlled by the output of the summing amplifier:

The **Level 1 Bistable** deenergizes above 15% power to enable the LPD and loss of load reactor trips and inhibit the high startup rate reactor trip.

The **Rod Drop Bistable** senses a rapid decrease in power by comparing the present power to power that has been processed through a time delay circuit. If the change is large enough (>4% in a 4 second period), the bistable trips. When the bistable trips, an automatic withdrawal prohibit (AWP) signal is transmitted to the control element drive control system and control room alarms are annunciated. The AWP is not safety-related.

9.1.9.3 Deviation Comparator

The deviation comparator circuit accepts outputs from both linear amplifiers, determines the difference between the output of the linear amplifiers, divides the difference by two (2), and transmits the resulting signal to the LPD calculator. The deviation comparator output is used by the LPD calculator to generate ASI. The ASI signal is used in the calculation of LPD.

9.1.9.4 Comparator Averager

The comparator averager receives inputs from the power summer of all four (4) linear power range safety channels and averages the signals. The average signal is supplied to the subchannel comparators where it is compared with the output of each linear amplifier. Local and control room annunciators are actuated if the deviation from the average exceeds a pre-determined value. This is a non safety-related signal.

9.1.9.5 Calibration and Testing

Each linear power range safety channel is equipped with two (2) switches and associated test circuitry which verifies the accuracy of the meter circuitry and allows testing of trip set points. The switches are located on the linear power range safety channel drawer. The level calibrate switch is a three (3) position switch (operate, zero, and calibrate) that is used to verify meter accuracy. In the operate position, detector input is supplied to the channel. The zero position is used to verify the meter indication for zero input. The calibrate position supplies a 200% signal used to verify meter full scale indication.

The trip test switch is a combination switch and potentiometer which adds a signal to the detector input signal to allow testing of the power range trip set points.

When either of the two (2) switches associated with the linear power range safety channel is placed in an abnormal position, an interlock trips the high voltage bistable. When the high voltage bistable is tripped, the TMLP, LPD, and VOPT reactor trips are deenergized.

9.1.9.6 High Voltage Power Supply

The high voltage power supply converts the drawer voltage into a high voltage dc output used for powering the uncompensated ion chambers. Each linear power range safety channel drawer is equipped with a zero (0) to 1000 Vdc meter which displays the power supply output. The high voltage can be adjusted from 450 to 1000 Vdc and is normally set at 750 Vdc. If voltage drops to 700 Vdc, the high voltage bistable trips.

9.1.10 Power Range Linear Control Channels

The two (2) power range linear control channels (Figure 9.1-9) are identical to the linear power range safety channels except for the channel outputs. Each non-safety related control channel supplies a signal to the RRS and a recorder in the control room.

In the RRS, control channel power is compared with turbine power to generate a power error signal. The rate of change of power error is used as an anticipatory signal for CEA motion.

Two (2) control room recorders, one (1) for each power range control channel, are installed to display power level. In addition to nuclear power, each recorder also displays ΔT power from the RPS channel A TMLP calculation.

Separate control channel upper and lower detector signals are sent to a power ratio calculator. The power ratio calculator provides two functions:

1. The power ratio calculator calculates a backup indication of ASI from the control channel input. ASI is defined as (flux in the bottom one half of the core minus flux in the top one half

of the core divided by total flux). The power ratio calculator supplies the ASI signal to a control room recorder. Potentiometers associated with the recorder allow the operator to set reference values and deviation limits for the ASI signal. The limits are derived from figures of allowable ASI in plant technical specifications.

2. It also selects the highest Q power (Q power is the highest of ΔT power or nuclear power from the four (4) LPD calculators). The power signal is used to generate pre-power dependent insertion limit (PPDIL) and power dependent insertion limit alarms (PDIL). These alarms help ensure that the CEAs are maintained at the proper position

9.1.11 Summary

The excore neutron monitoring system consists of the safety-related wide range logarithmic channels, the safety-related linear power range safety channel, and the non-safety related power range linear control channel. These instruments provide indication of neutron power from the source level to 200% full power. The wide range logarithmic power channel supplies a high startup rate reactor trip signal to the RPS, and the linear power range safety channel provides a TMLP reactor trip input, a high reactor power reactor trip signal, a loss of load reactor trip input, and an input signal to the LPD reactor trip. The power range linear control channel provides a power signal to the RRS and indication of ASI.

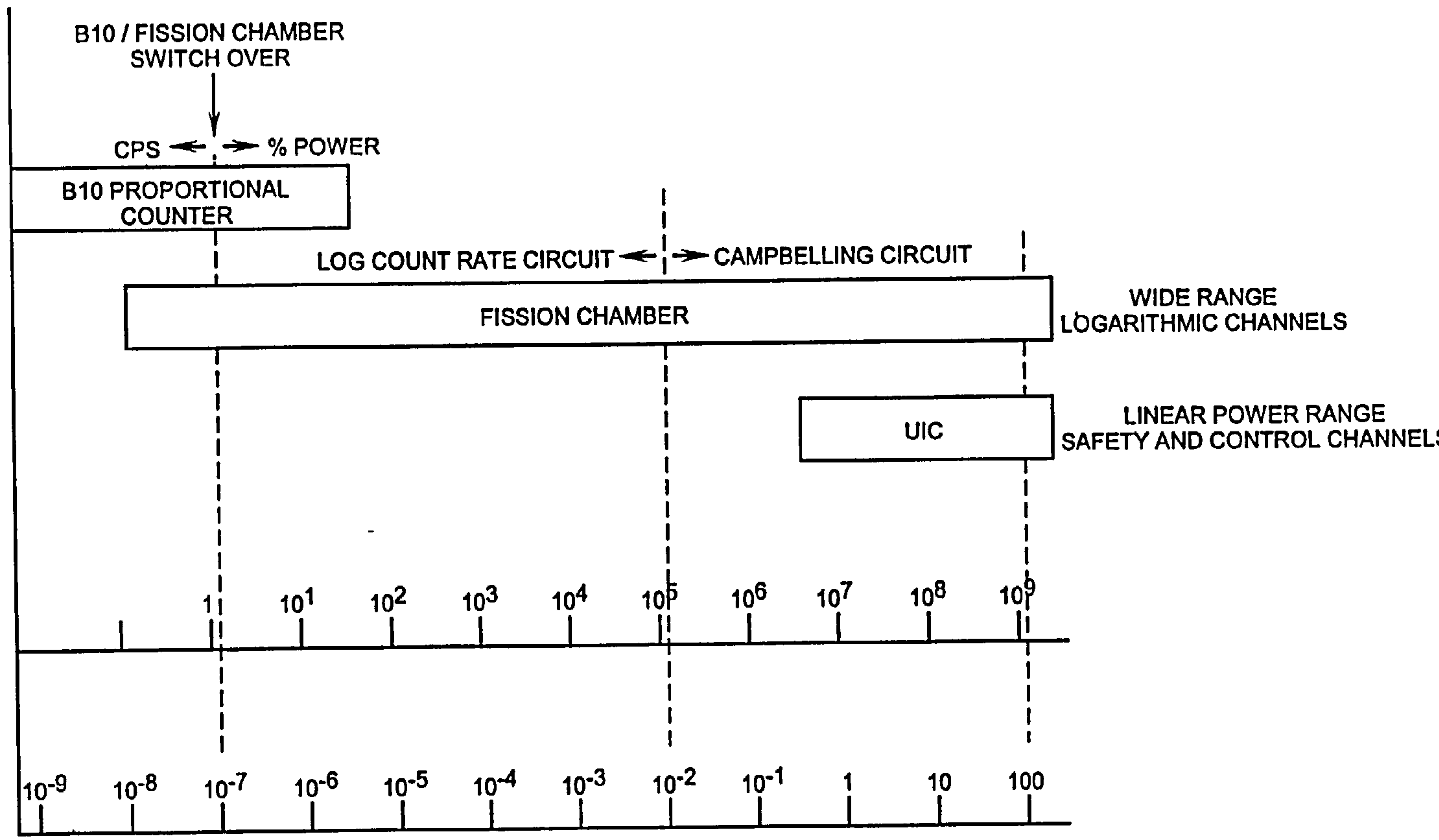

Figure 9.1-1 Typical Channel Flux Coverage With Detectors

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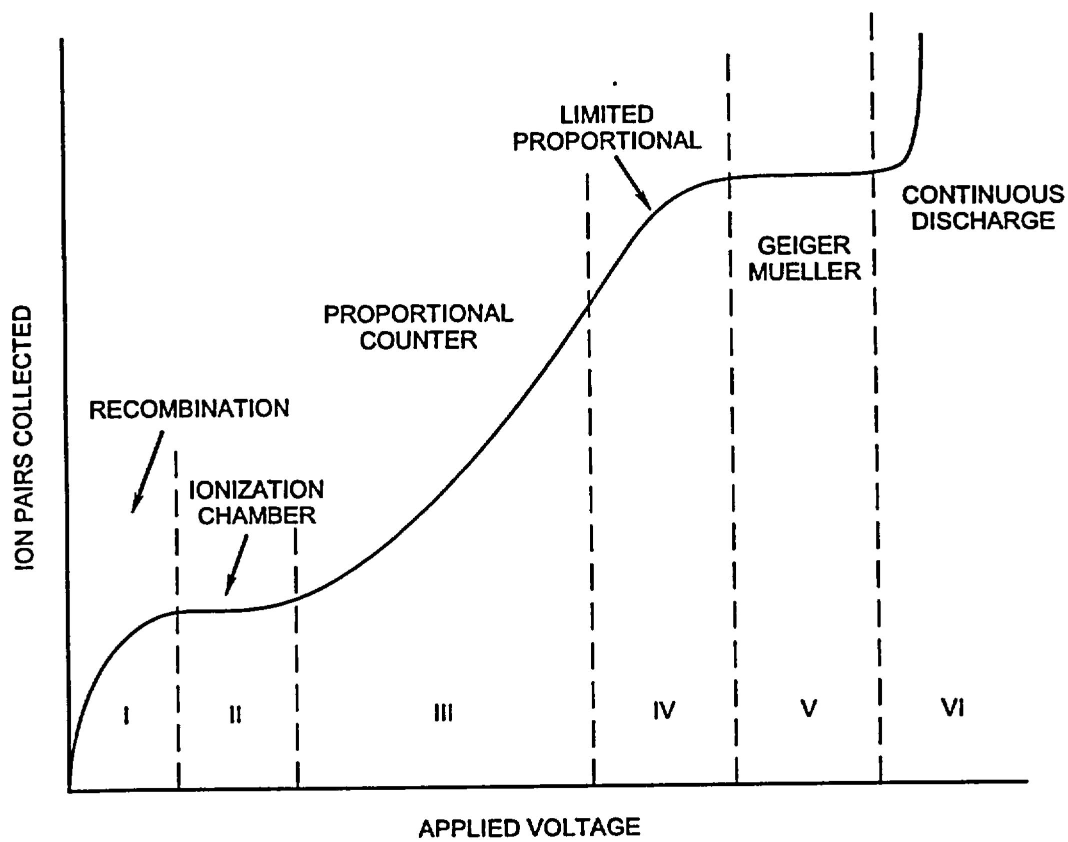
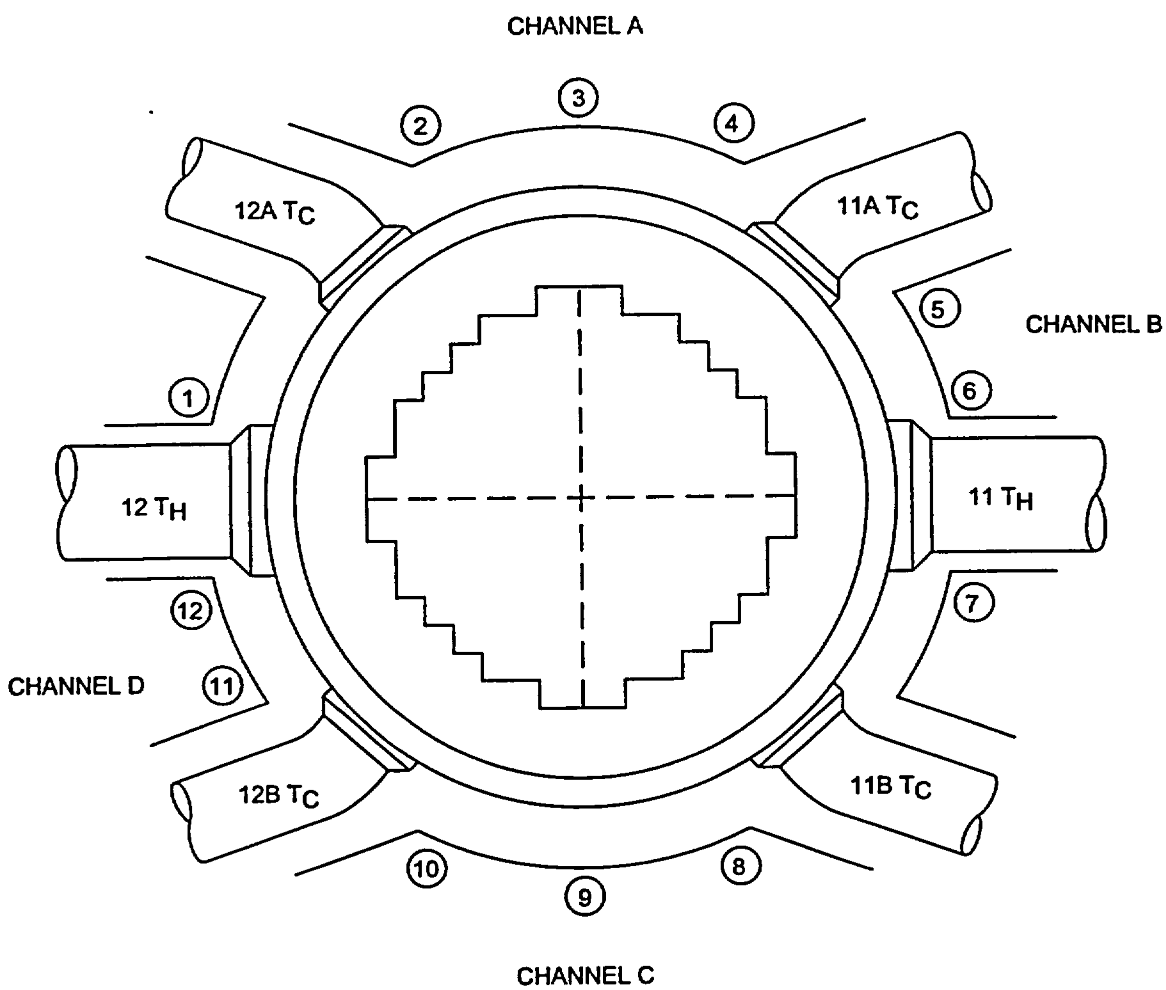


GAS AMPLIFICATION CURVE

Figure 9.1-2 Ion Pairs Versus Applied Voltage



WIDE RANGE LOG CHANNELS-3,5,9,11
LINEAR POWER RANGE SAFETY CHANNELS-2,6,8,12
LINEAR POWER RANGE CONTROL CHANNELS-4,7
SPARE LOCATIONS-1,10

Figure 9.1-3 Excore Detector Location

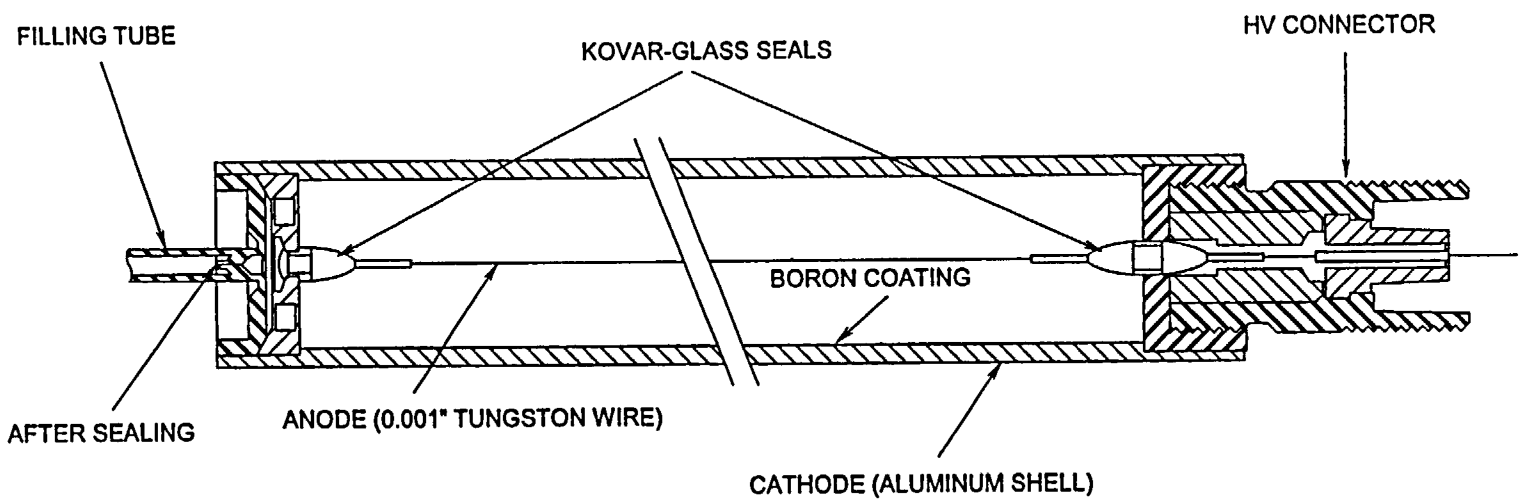


Figure 9.1-4 Typical B10 Proportional Counter

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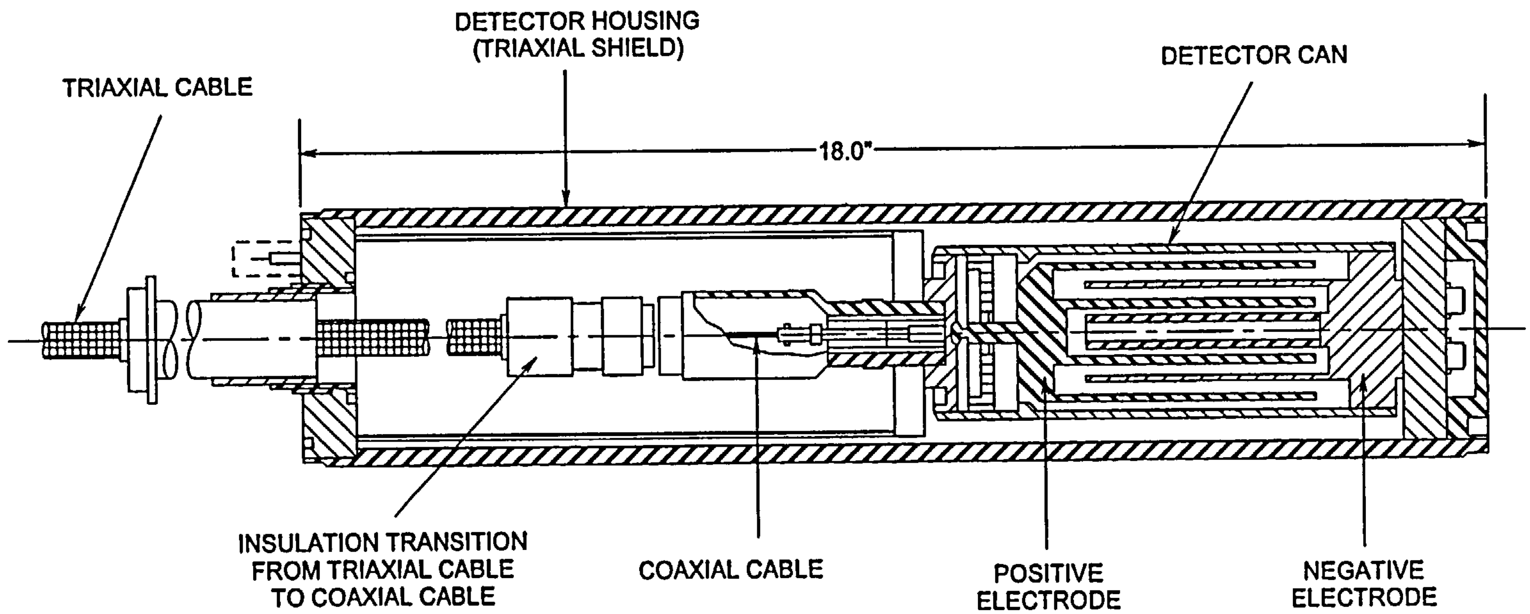

Figure 9.1-5 Fission Chamber (Neutron Sensitivity 0.7 Counts/NV)

1000-09

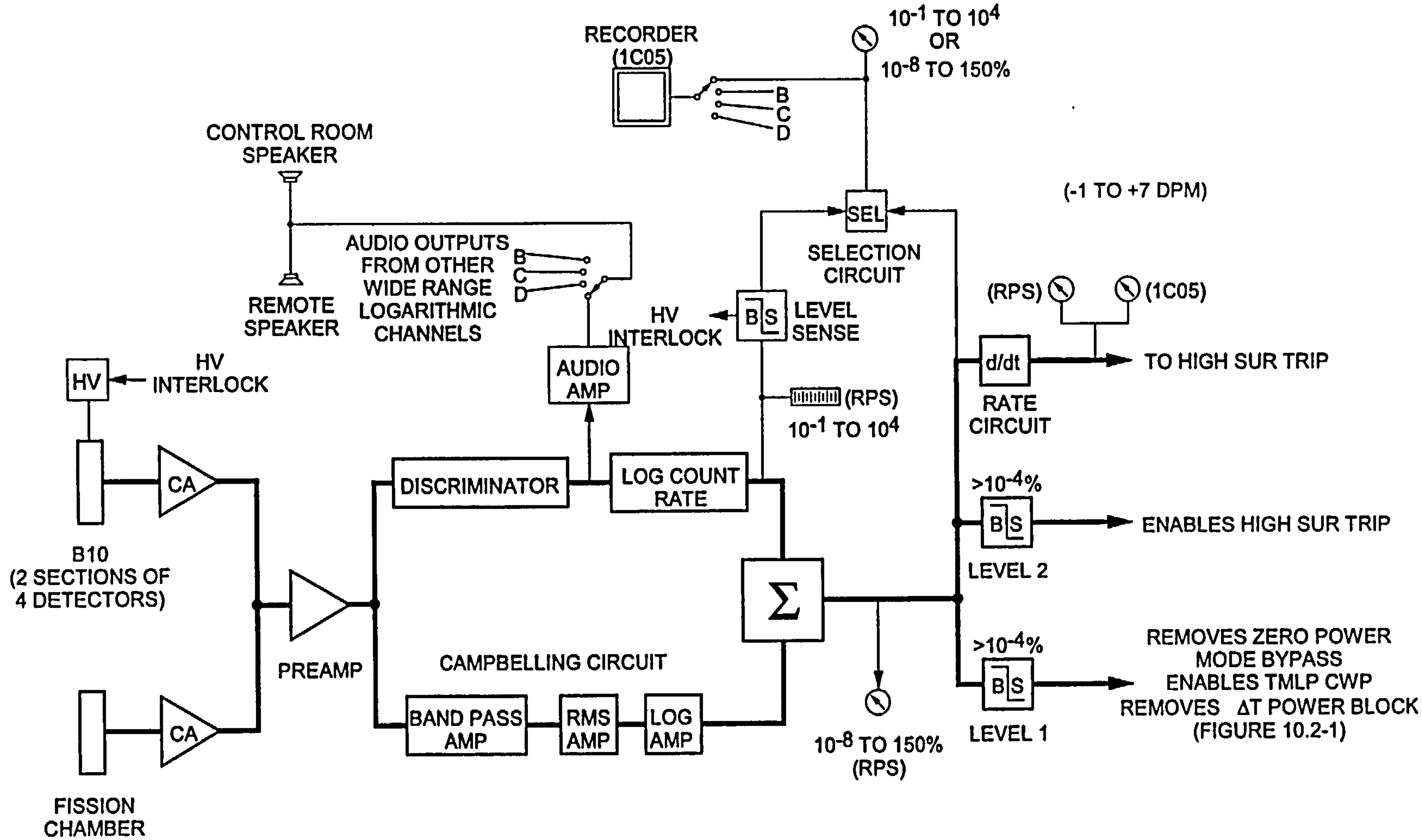

Figure 9 1-6 Excore NI Wide Range Logarithmic Channel Block Diagram

1000-C

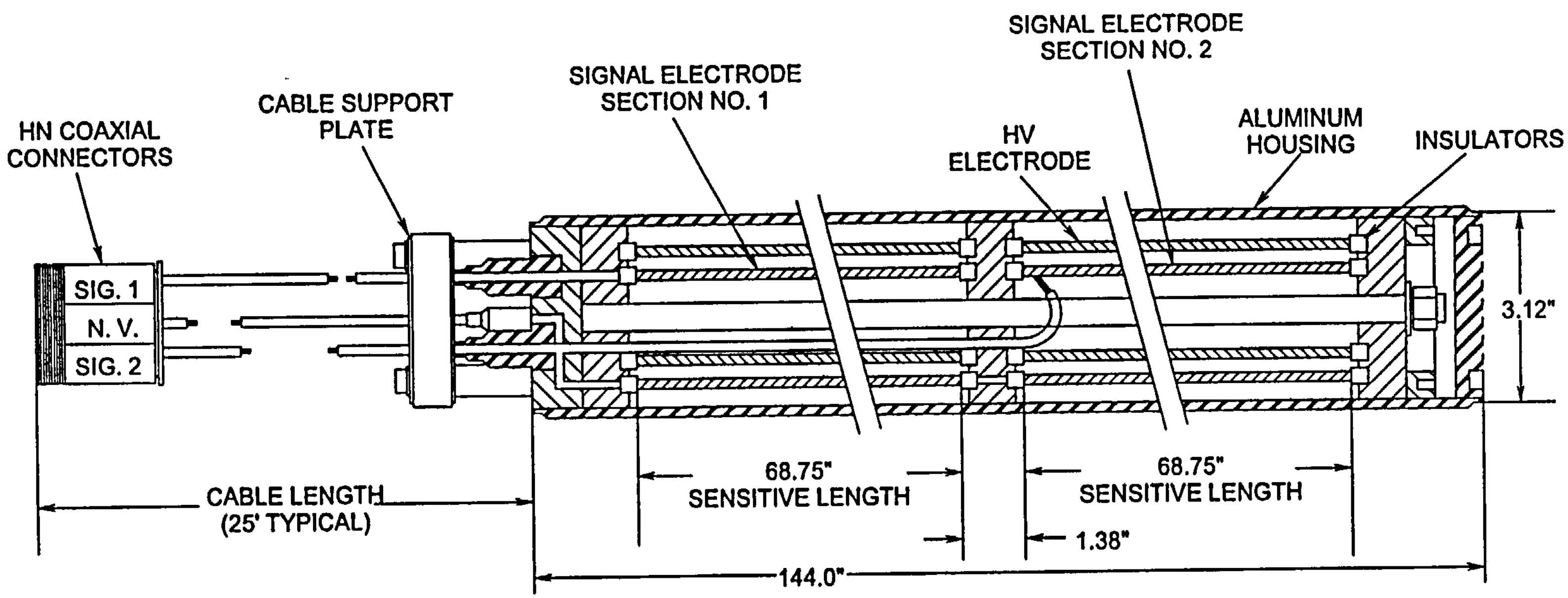

Figure 9.1-7 Uncompensated Ionization Chamber
Neutron Sensitivity 3.5E-13 A/NV
Gamma Sensitivity 1.2E-10 A/NV

1000-09

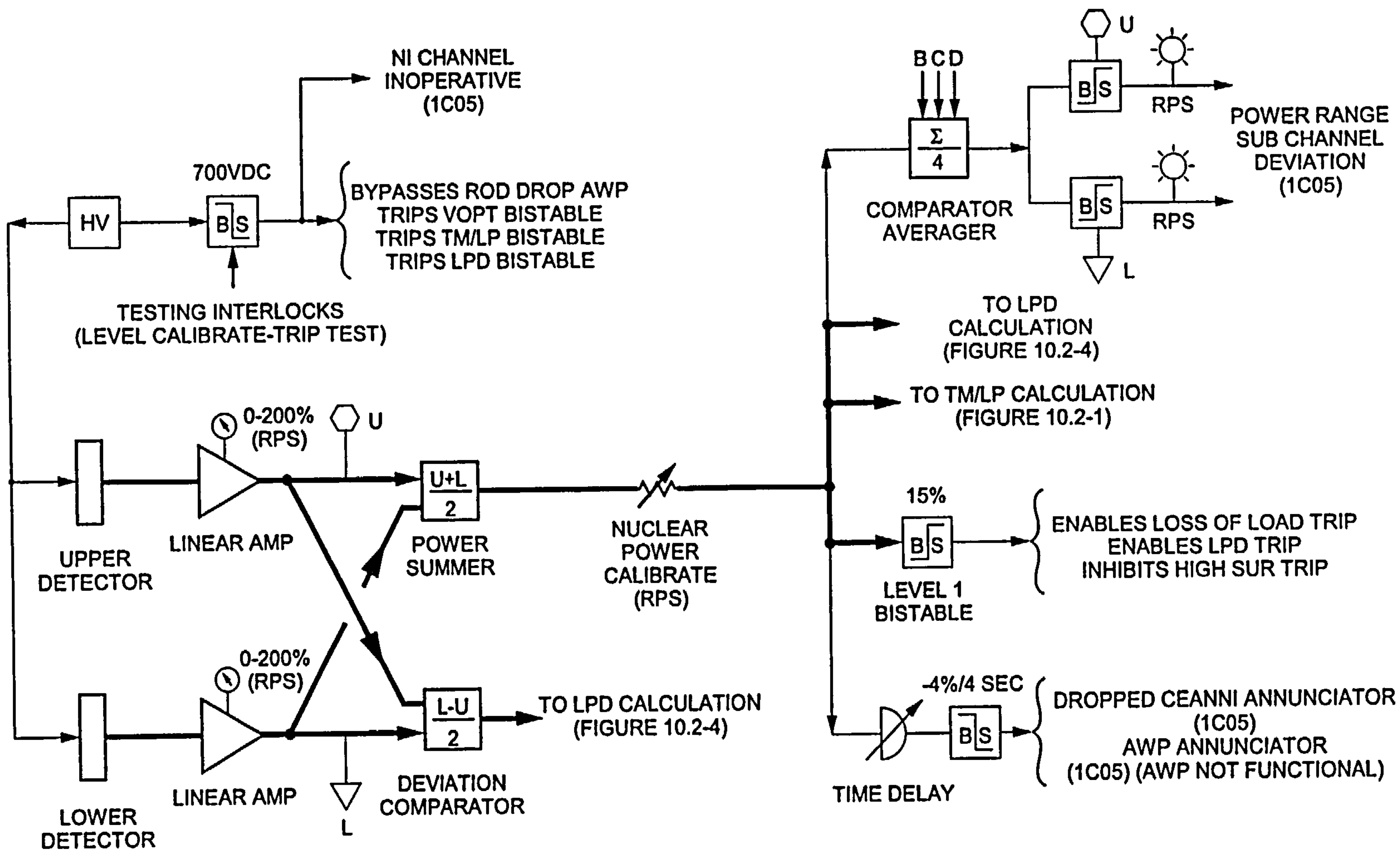

Figure 9.1-8 Excore NI Narrow Range Linear Channel Block Diagram

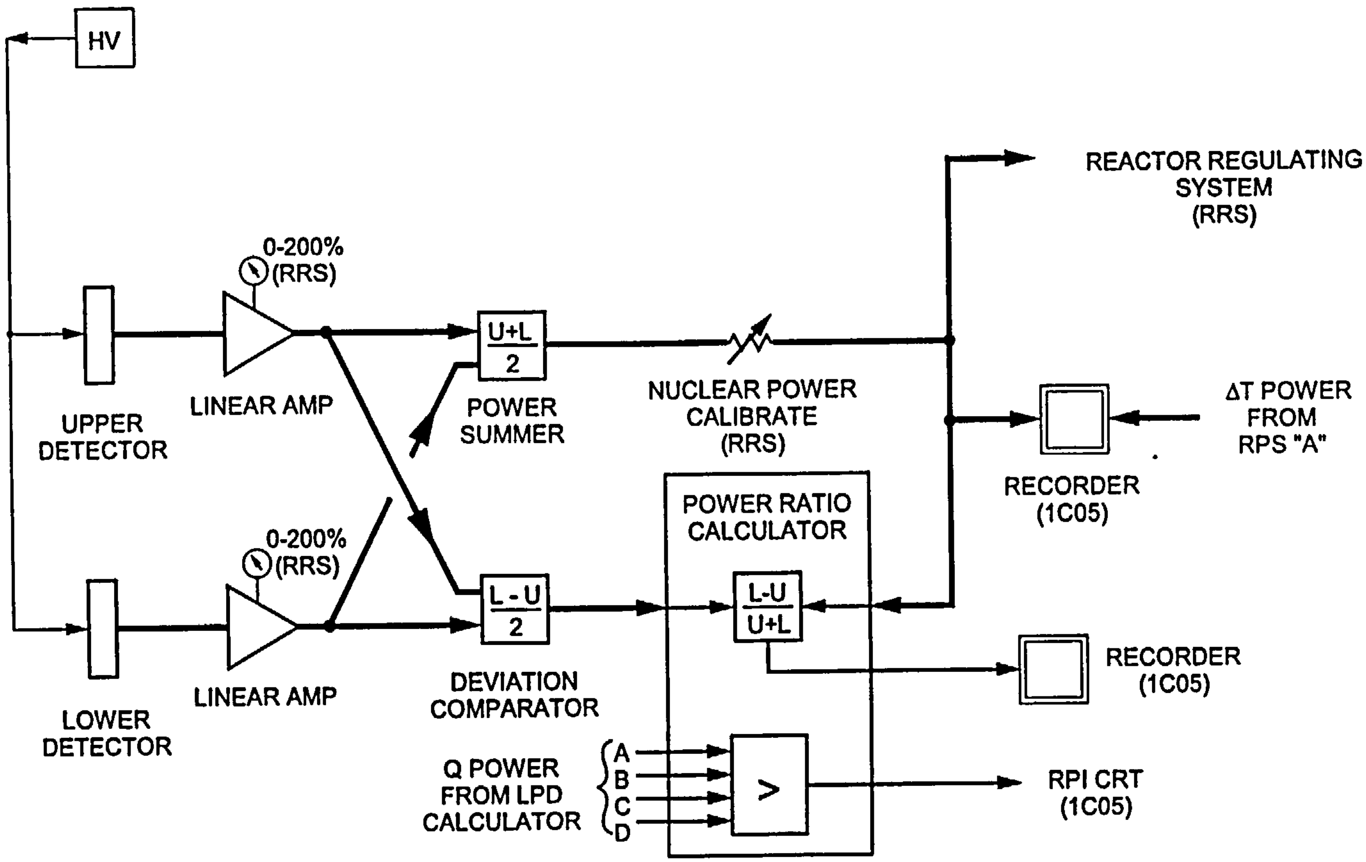

Figure 9.1-9 Linear Power Control Channel Block Diagram

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9.2 INCORE NEUTRON MONITORING SYSTEM

Learning Objectives:

1. Describe the basic operation of the incore neutron monitoring system (ICI).
2. Explain the functions of the incore neutron monitoring system.
3. Explain the functions of the core exit thermocouple system (CET).

9.2.1 Introduction

The incore neutron monitoring system continuously monitors the core neutron level to provide information on the axial and radial flux distribution within the core. The system consists of a fixed incore detector system, core exit thermocouples, amplifiers for both systems, and associated hardware with computer interfaces. In addition to sensing neutrons, the incore system also provides fuel assembly exit temperature measurements.

The functions of the ICI system are as follows:

1. To determine the gross power distribution in the core at different operating conditions over the range from 10 to 125% average reactor power,
2. To provide data to estimate the fuel burnup in each fuel assembly,
3. To provide information to guide the operation of control element assemblies in the control of xenon oscillations and to ensure that power peaking factors do not exceed allowable limits during this maneuvering of the control element assemblies,
4. To provide data for the evaluation of thermal margins in the core,
5. To provide data which will be used to verify core power distribution is consistent with calculated values,
6. To provide data to periodically normalize the excore detector readings to assure that they indicate the correct top to bottom distribution and correct power distribution among quadrants and
7. To provide signals to alert the operator to abnormal or unexpected occurrences in the core.

9.2.2 Neutron Detection

When the element rhodium is bombarded with a neutron flux, it becomes radioactive and will decay by emitting a beta particle. The reaction takes place as follows:

$$_{45}Rh^{103} + {}_0n^1 \rightarrow {}_{45}Rh^{104} \rightarrow$$

$$_{46}Pd^{104} + \beta + \text{energy}$$

Furthermore, if the rhodium is insulated from electrical ground, then the emission of the beta particle (electron) will represent a charge deficiency that is proportional to the number of neutron reactions. A method of measuring this charge exists when the rhodium detector material is connected to ground, and the flow of electrons required to replace the emitted beta particles is measured. A simplified version of the circuit needed to accomplish this function is shown in Figure 9.2-1. Since no external source of detector power is required, the neutron detector is self-powered. The neutron detector response time is proportional to the decay of the $_{45}Rh^{104}$ isotope. The decay scheme for rhodium involves two half-lives, and is illustrated in Figure 9.2-2. The majority (~93%) of the rhodium-neutron reactions decay to palladium by beta emission in 42 seconds, while a small number of the reactions (~7%) requires four and four-tenths (4.4) minutes to complete the transmutation. As previously stated, these two (2) half-lives effect the detector response time, and are of particular interest during changing neutron flux levels. As seen in Figure 9.2-3, approximately five (5) minutes is required for the detector's output to reach the new equilibrium output if a step change in power (flux) level occurs. This long time period precludes the use of the incore detector's output in core protection systems.

The self powered neutron detector signal is influenced by electrons from sources other than the beta decay of $_{45}Rh^{104}$. Gammas directly from fission, fission product decay, or neutron capture in the $_{45}Rh^{103}$ detector, produce electrons by Compton scattering, the photoelectric effect, or pair production. A background detector is installed in the incore detector assembly and is used to correct the self powered neutron detector's output for gamma induced current. The background detector is subject to the same gamma field as the neutron detectors. The plant computer uses information from the background detectors to correct the output of the detector signal for gamma radiation.

9.2.3 Signal Processing

Each incore detector assembly provides signals to the plant computer for analysis. Figure 9.2-4 illustrates the interface between the inputs from the detector assemblies and the plant computer, and is typical of all incore detector inputs.

The output current from the neutron detectors and the background detector is routed through a 100,000 ohm resistor to convert the current signal to a voltage signal. The voltage output is supplied to a multiplexor that connects a specific input signal to an analog to digital converter. The analog to digital converter changes the signal to a digital voltage that is used by the computer. Since the thermocouple output is a millivolt signal, a direct connection can be made to the multiplexor.

9.2.4 Computer Processing

The plant computer utilizes the neutron and background detector inputs, constants, and correction factors to calculate neutron flux at 20, 40, 60, and 80% levels of core height. The formula used to calculate neutron flux at a particular core elevation is:

$$\Phi = I \div [(S)(L)(Ks)(Kb)(Ko)]$$

Where:

I = the neutron detector input current.

S = the thermal neutron sensitivity of the $_{45}Rh^{103}$ detector and is equal to $1.15X10^{-21}$ amperes/nv/cm.

L = detector length.

K_s = a correction factor for the decrease in $_{45}Rh^{103}$ due to detector burnup.

K_b = a correction factor for the effects of γ, β reactions. K_b is calculated by the plant computer using the signals from the background detector.

K_o = a correction factor for the effects of the change in neutron energies over core life. As the neutron energy changes, the $_{45}Rh^{103}$ absorption cross section changes.

The computer uses the calculated neutron flux (ϕ) in a resident program called INCA (CENPD-145 provides a detailed description of INCA software). INCA calculates the power in uninstrumented fuel assemblies, the power in multiple horizontal core planes, and the value of azimuthal power tilt (Tq)

Azimuthal tilt is calculated from the output of symmetric detectors and is defined as the maximum difference between the power generated in any core quadrant (upper or lower) and the average power in that half (upper or lower) of the core. Although the definition is wordy, it isn't difficult to calculate the value of azimuthal tilt. Assume that the following numbers are values of power in each quadrant in the upper one half of the core:

Quadrant 1 = 101%
Quadrant 2 = 99%
Quadrant 3 = 96.5%
Quadrant 4 = 99%

The average power of all the quadrants is (101 +99+96.5+99) ÷ 4 = 98.875. The maximum difference between the power generated in any quadrant and the average power in all quadrants is the difference between quadrant 3 and the average quadrant power and is equal to 2.375%. Plant technical specifications limit the value of azimuthal tilt.

INCA uses azimuthal tilt and the axial power calculations to calculate the hot channel heat flux, peak pin power, and the radial peaking factors. The radial peaking factors are the unrodded planar radial peaking factor (Fxy) and the unrodded integrated radial peaking factor (Fr).

The unrodded planar radial peaking factor (Fxy) is defined as the maximum ratio of the peak to average power density of the individual fuel rods in any of the unrodded horizontal planes, excluding tilt. The total planar radial peaking factor, F^Txy, is a function of the unrodded planar radial peaking factor and azimuthal tilt ($F^Txy = Fxy \times (1+Tq)$) and is used by the INCA program to calculate hot channel heat flux. Plant technical specifications also limit the value of the total planar radial peaking factor.

The unrodded integrated radial peaking factor, Fr, is defined as the ratio of he peak pin power to the average pin power in an unrodded core, excluding tilt. Again, the total unrodded integrated radial peaking factor, F^Tr, is a function of the unrodded integrated radial peaking factor and azimuthal tilt ($F^Tr = Fr \times (1+Tq)$). Plant technical specifications also limit the value of the total unrodded integrated radial peaking factor.

The factors described in the preceding paragraphs affect the core's heat flux and are assumed values in the calculations of the specified acceptable fuel design limits (DNBR and kW/ft.) and the LOCA acceptance criteria. If these factors are less conservative that the values used in the calculations, the core is operating in an unanalyzed situation. If a transient or accident occurs, the specified acceptable fuel design limits or the LOCA acceptance criteria may not be met.

Periodic surveillances are performed by the plant staff to ensure that azimuthal tilt, total unrodded planar radial peaking factor and the unrodded integrated radial peaking factor are within assumed values. Since the incore detectors are used to determine these values, plant technical specifications require the operability of the system.

9.2.5 Core Exit Thermocouples

A cromel-alumel thermocouple is located at the top of each incore detector assembly and measures the temperature of the water exiting the control element assembly (CEA) guide tube at 45 different locations. The thermocouple has a maximum operating temperature of 2300°F and an approximate output voltage of 55 millivolts.

Each core exit thermocouple (CET) is located in a CEA guide tube about one (1) foot above the active core and is influenced by water that has not passed along the fuel rods. Under full RCS flow conditions, the CETs read about 10 to 15°F less than the Th indication. Under reduced flow shutdown cooling system operations, conduction of heat into the CEA guide tube causes the CET to closely track the Th reading.

CET temperatures are used by the operating staff during the implementation of emergency operating procedures to determine:

1. Proper core cooling during natural circulation events,
2. Core subcooling margin during a loss of coolant event and
3. Core uncovery (indicated by superheated CET readings during inadequate core cooling conditions.

9.2.6 Mechanical Construction

The incore detector contains four (4) rhodium neutron detectors and one (1) Cr-Al thermocouple. The four rhodium detectors have their centers spaced at 20%, 40%, 60%, and 80% of the active core height as seen in Figure 9.2-5. Thermocouples are located at the top of the detector assembly so they can measure the outlet coolant temperature of the instrumented fuel assemblies. The arrangement of the incore detector assemblies is shown in Figure 9.2-6.

The detector assemblies are inserted through the instrumentation nozzles. The assemblies go into guide tubes and finally into zircalloy thimbles within the fuel assemblies. The detectors have to be bent (amount varies with different assemblies) to reach the required thimbles. The detector is located within the core as shown in Figure 9.2-7. During refueling, the detector assemblies are withdrawn into their guide tubes and are lifted out of the vessel together with the upper guide structure by means of a lift rig.

9.2.7 Summary

The incore monitoring system provides continuous information pertaining to axial and radial flux distributions. This data is provided by self powered rhodium detectors at various locations throughout the core. In addition, fuel assembly exit temperatures are measured to provide temperature indications during emergencies.

$$^{103}_{45}\text{RH} + ^{1}_{0}\text{n} \text{ --> } ^{104}_{45}\text{Rh} \text{ --> } ^{104}_{46}\text{Pd} + ^{0}_{-1}\beta + \text{ENERGY}$$

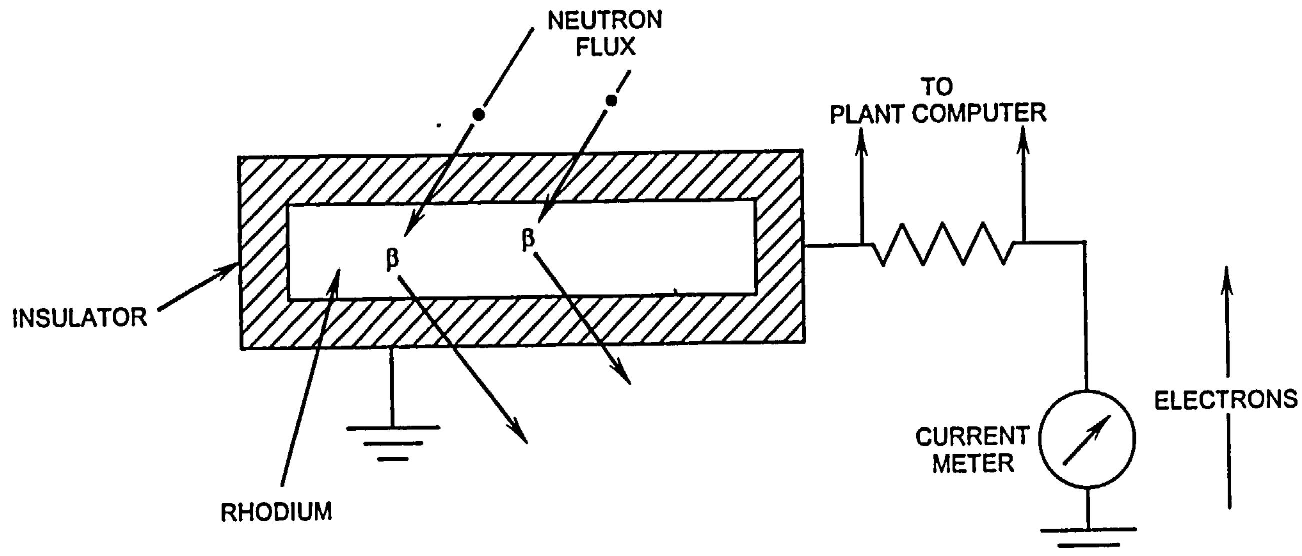

Figure 9.2-1 Self Powered Neutron Detector

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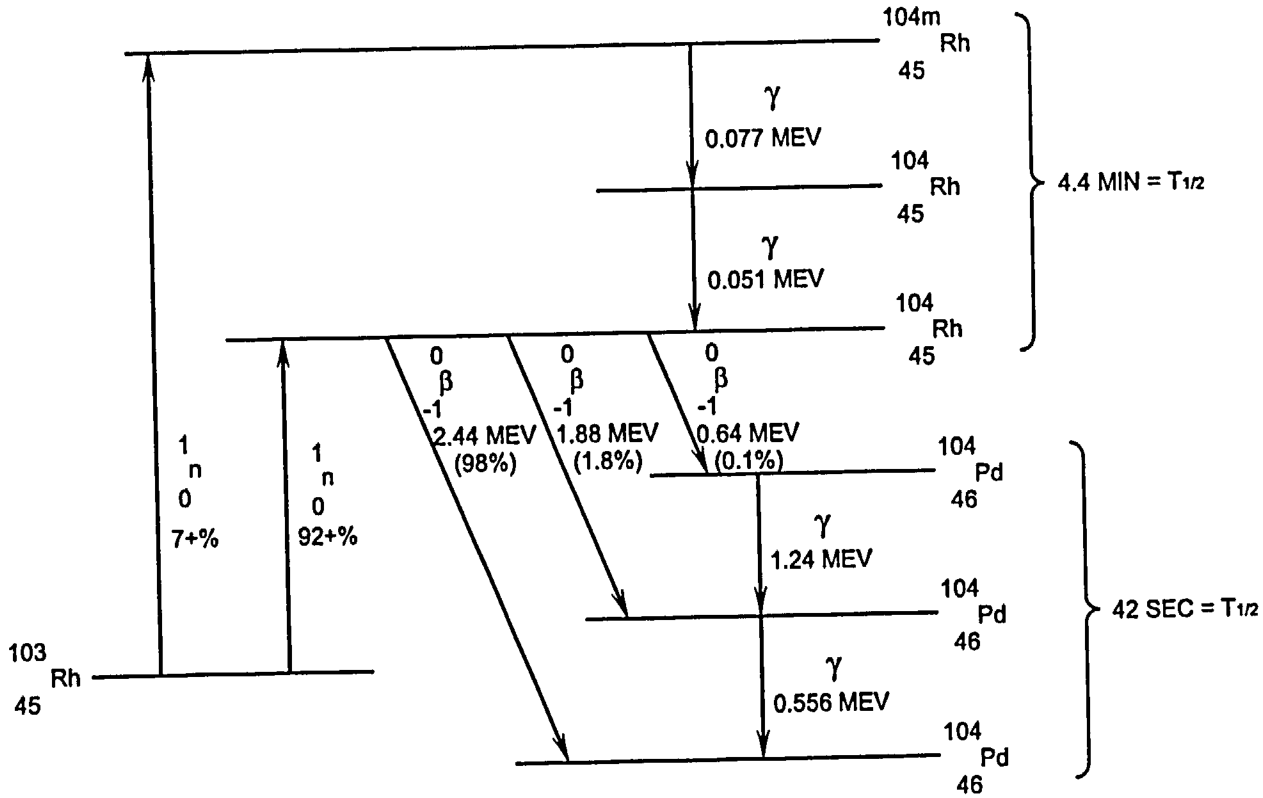

Figure 9.2-2 Rhodium Decay Scheme

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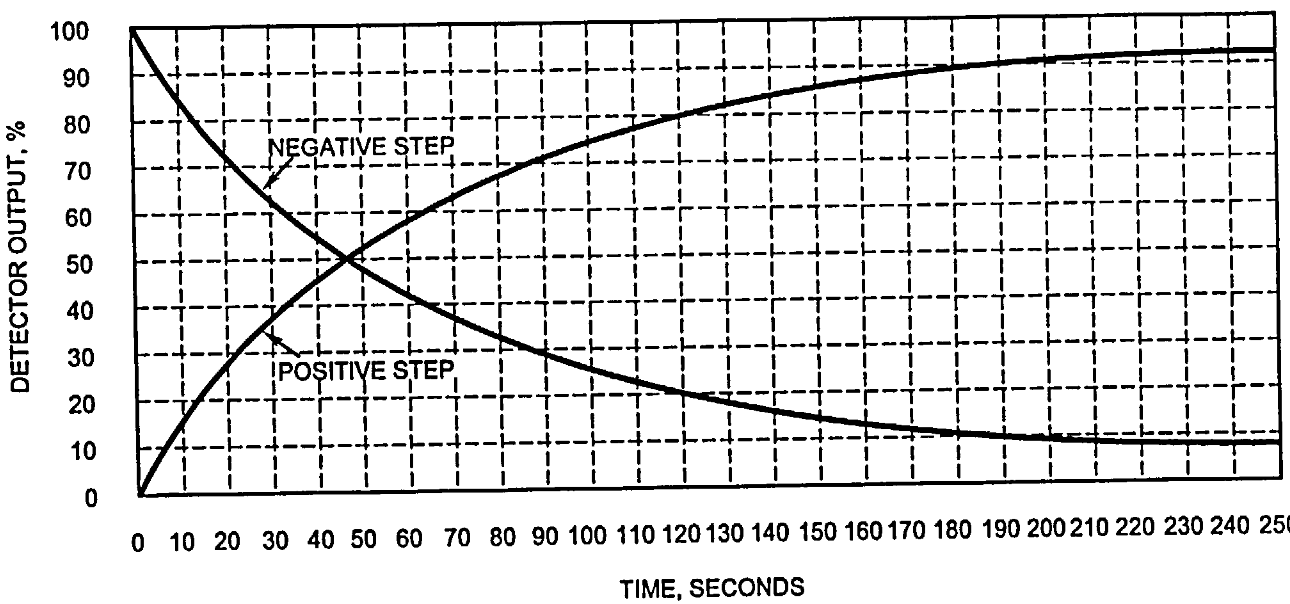

Figure 9.2-3 Rhodium Detector Response

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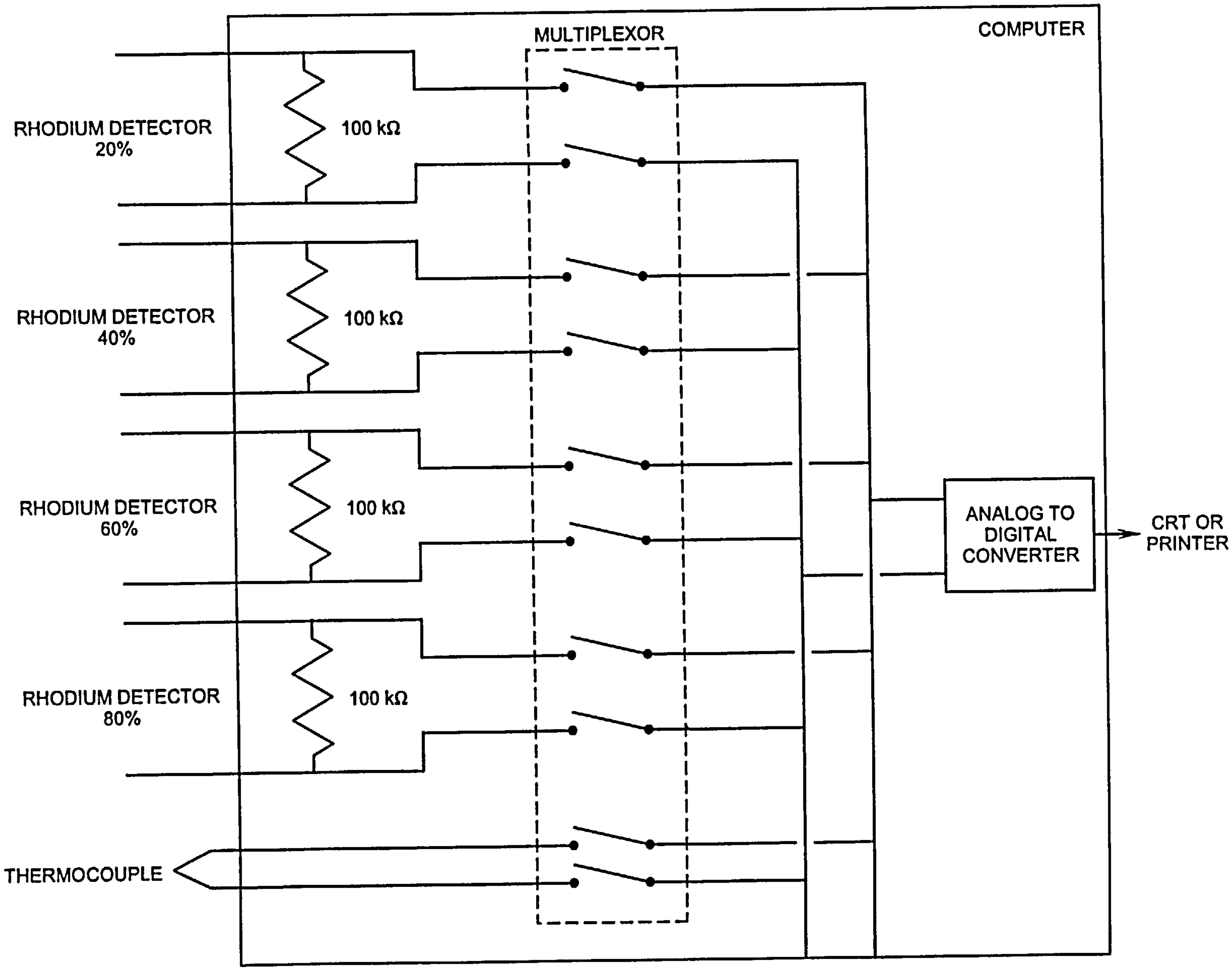

Figure 9.2-4 Incore Detector Interface With Plant Computer

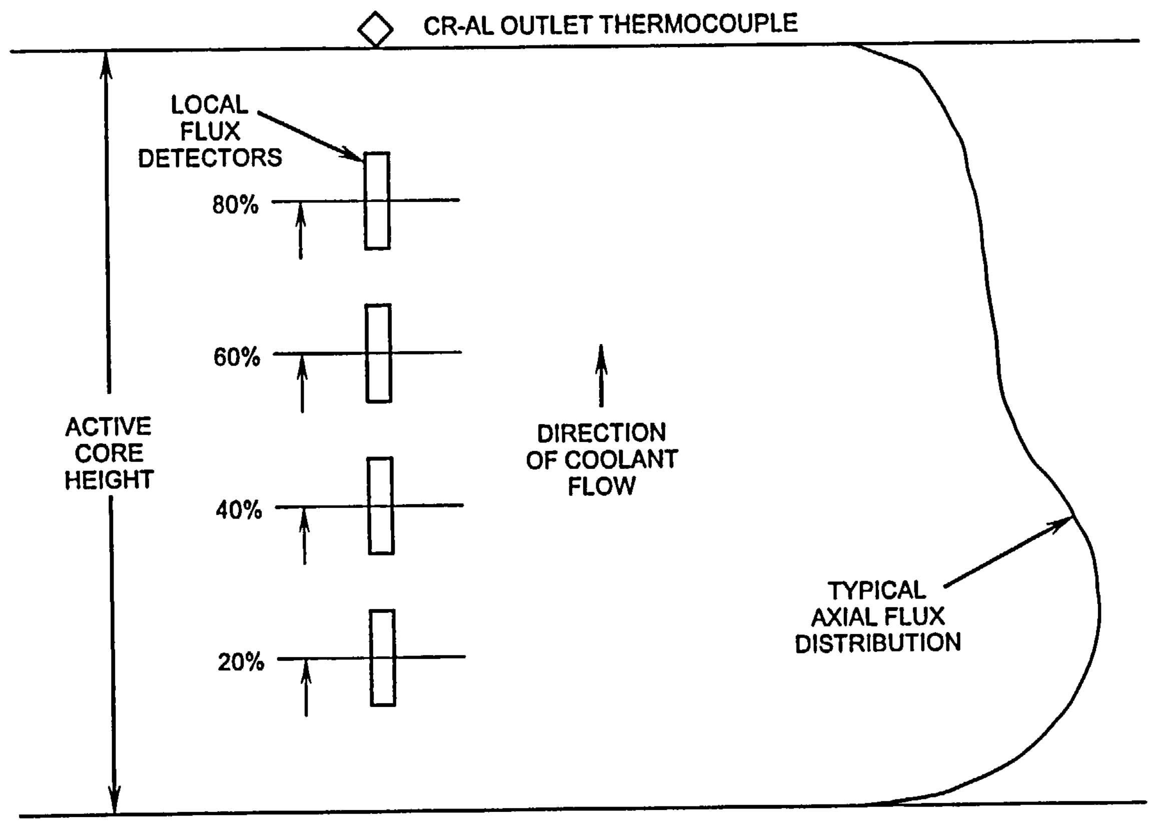

Figure 9.2-5 Incore Detector Axial Arrangement

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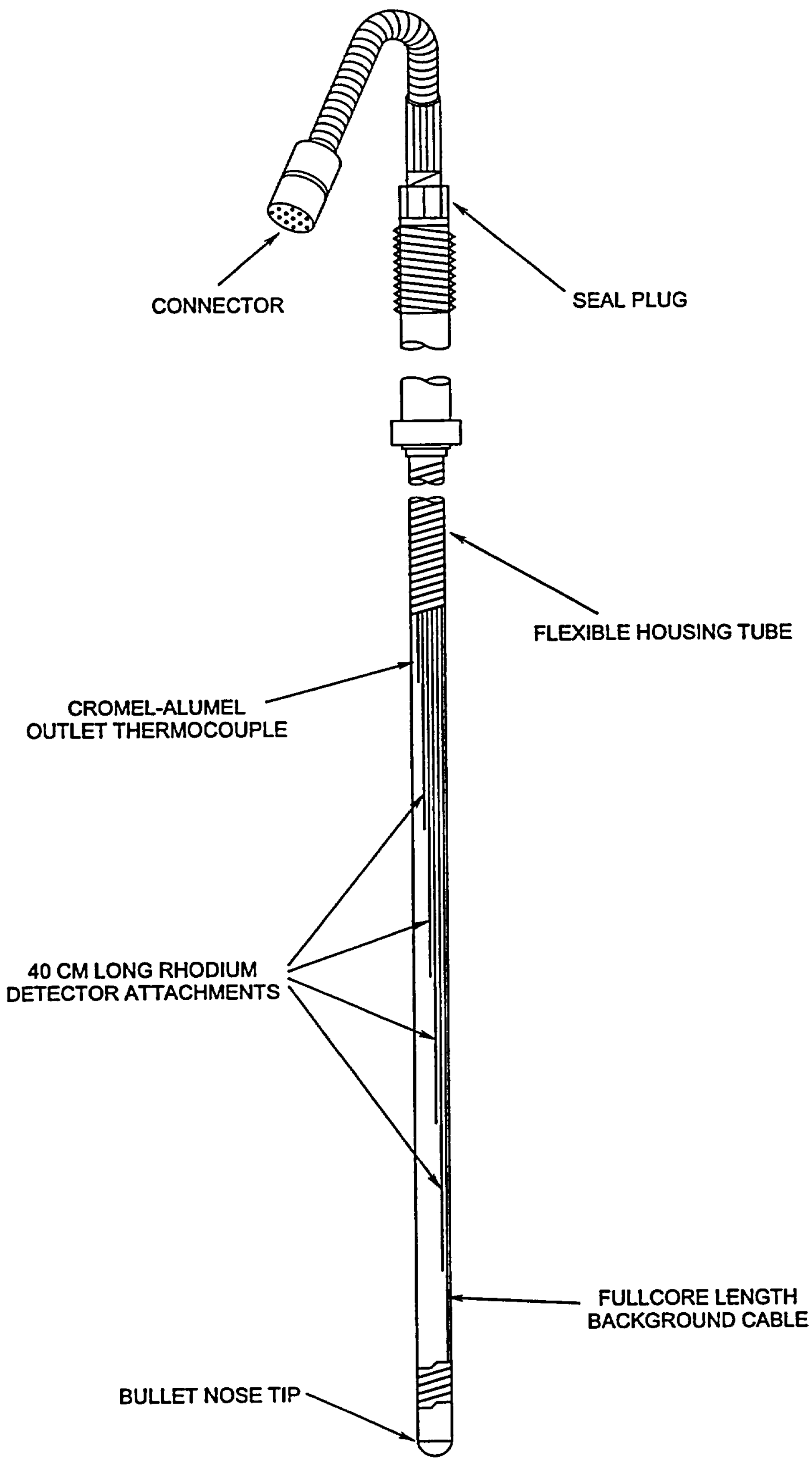

Figure 9.2-6 Incore Detector Assembly

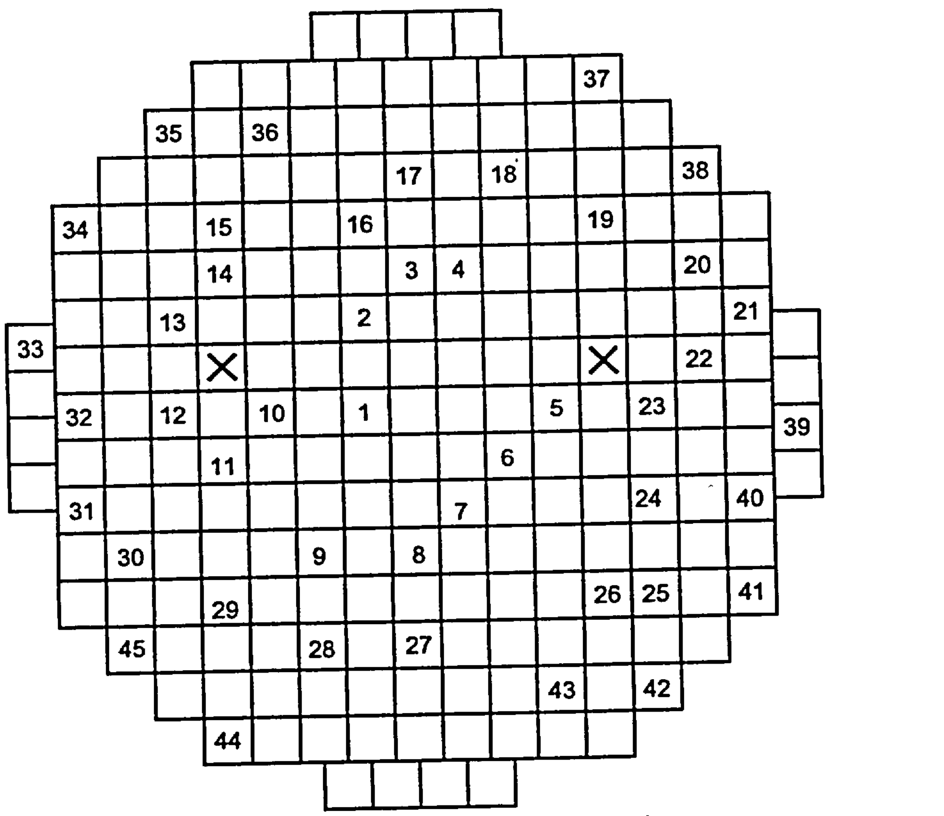

Figure 9.2-7 Incore Detector Location

Combustion Engineering Technology
Cross Training Course Manual

Chapter 10

REACTOR PROTECTION SYSTEMS

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10.1 REACTOR PROTECTION SYSTEM

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10.1 REACTOR PROTECTION SYSTEM

Learning Objectives:

1. State the purpose of the reactor protection system (RPS).

2. Define the term anticipated operational occurrence (AOO).

3. Explain how the following design features are incorporated into the RPS:

   a. Single Failure Criterion
   b. Testability
   c. Redundancy

4. Explain the purpose of each reactor trip.

5. Explain how the two (2) out of four (4) RPS trip logic is derived.

6. Explain the reactor trip circuit breaker (RTB) trip logic.

7. Explain the effect of placing a RPS trip in trip inhibit.

8. List the trips that are automatically bypassed.

9. List the trips that are bypassed by the zero power mode bypass.

10. State the devices that are actuated by the diverse scram system (DSS).

10.1.1 Introduction

The purpose of the RPS is to insure that plant safety limits are not violated during AOOs. The plant safety limits are departure from nucleate boiling (DNB), peak linear heat rate (LHR), and reactor coolant system (RCS) pressure. The first two limits protect the cladding boundary and the last limit protects the RCS boundary. AOOs are defined as those conditions which are expected to occur one or more times during the life of the nuclear power unit. Examples of AOOs are turbine trips, loss of condenser vacuum, and a complete loss of offsite power.

The RPS consists of four (4) separate channels with each of the channels receiving independent safety related input parameters. If any two (2) of the four (4) channels sense that a parameter is at set point, a reactor trip will result.

The two (2) out of four (4) reactor trip logic combined with the four (4) separate inputs provide RPS redundancy and reliability. If only one transmitter input system were used and the transmitter failed in a non-conservative direction, then the RPS would not trip the reactor.

The use of a two (2) out of four (4) system using four (4) separate input channels as opposed to using two (2) separate input channels and a one (1) out of two (2) trip logic improves the ability of the RPS to generate a reactor trip signal. In a one (1) out of two (2) system, however, if an input signal fails in the conservative direction an unnecessary reactor trip will result. Also, during testing of a one (1) out of two (2) system, the RPS is reduced to a one (1) sensor system. The next logical step would be the addition of a third channel and a third sensor. If a two (2) out of three (3) logic is used in this system, a signal failure in either the conservative or non-conservative direction will neither generate an unnecessary reactor trip nor prevent a needed trip.

As stated above, a two (2) out of three (3) system will satisfy the requirement of safety function operability even in the event of a single failure. However, a two (2) out of three (3) system loses some of its desirable characteristics during testing. To test a two (2) out of three (3) system, the channel to be tested is placed in a tripped condition. Tripping a channel reduces the RPS to a one (1) out of two (2) logic.

An additional channel and a two (2) out of four (4) trip logic will have all the desirable features of a three (3) channel system. One (1) channel may be bypassed (instead of tripped) for testing or maintenance. In this condition, the RPS functions as a two (2) out of three (3) system.

To insure safety limit protection, the RPS must fail to a safe condition upon a loss of power. To meet this requirement, the RPS is designed as a de-energize to actuate system. If RPS power is lost, a reactor trip will result. The RPS is powered from four (4) separate 120 Vac inverter supplied buses.

10.1.2 Purposes of Reactor Trips

10.1.2.1 Variable Overpower Trip (VOPT)

The VOPT provides core protection against positive reactivity excursions that are too rapid for high pressurizer pressure or the thermal margin low pressure (TMLP) trip to protect against. The following events require variable overpower protection:

1. Uncontrolled CEA withdrawal event,
2. Excess load (excess heat removal by the secondary),
3. Excess feedwater heat removal event,
4. CEA ejection event and
5. Main steam line break outside of containment.

The first three (3) events are AOOs, and fuel integrity is maintained. The fourth and fifth are accidents and limited fuel damage may occur.

The VOPT ensures that the departure from nucleate boiling ratio (DNBR), linear heat rate (kW/ft) and RCS pressure safety limits are maintained during normal operation and AOOs. In conjunction with the engineered safety features actuation system (ESFAS) the consequences of the main steam line break accident and the CEA ejection accidents will be acceptable.

10.1.2.2 High Start-up Rate

The high start-up rate trip is used to trip the reactor when wide range logarithmic power indicates an excessive rate of change. The high start-up rate trip provides a backup to the VOPT to ensure that the DNBR, kW/ft, and RCS pressure safety limits are maintained during start-up conditions. The high start-up rate trip minimizes transients for events such as a continuous CEA withdrawal or a boron dilution event from low power levels.

10.1.2.3 Low RCS Flow

The low RCS flow trip provides protection during the following events:

1. Loss of RCS flow,
2. Loss of non-vital ac power,
3. Reactor coolant pump (RCP) seized shaft and
4. RCP sheared shaft.

The loss of RCS flow and the loss of non-vital ac power are AOOs, and the DNBR safety limit is maintained. The seized RCP shaft and the sheared shaft are accidents that may result in fuel damage.

10.1.2.4 Thermal Margin Low Pressure (TMLP)

The TMLP trip prevents exceeding the DNBR safety limit during AOOs and aids the ESFAS during certain accidents.

The following events require TMLP protection:

1. Excess load (inadvertent opening of an atmospheric steam dump valve),
2. RCS depressurization (inadvertent opening of the spray, power operated relief valves, or pressurizer safety valves),
3. Steam generator tube rupture and
4. Loss of coolant accident.

The first two (2) events are AOOs, and DNBR is maintained. The third and fourth events are accidents, and limited fuel damage may occur.

10.1.2.5 Local Power Density (LPD)

The LPD trip ensures that axial peaking, such as that due to axial xenon oscillations, will not cause fuel damage. It ensures that neither a DNBR less than the safety limit nor a peak kW/ft which corresponds to the temperature for centerline fuel melting will occur. This trip is the primary protection against fuel centerline melting.

10.1.2.6 High Pressurizer Pressure

The high pressurizer pressure trip, in conjunction with the pressurizer and main steam safety valves, provides protection against over pressure conditions in the RCS during the following events:

1. Loss of condenser vacuum with a concurrent loss of offsite power,
2. Turbine trip from 102% power,
3. Feedwater system breaks between the steam generator and feedwater inlet check valve,
4. CEA withdrawal and
5. Loss of feedwater flow.

The high pressurizer pressure trip assures that the RCS pressure limit will not be exceeded during AOOs, and in conjunction with the ESFAS, that the consequences of accidents will be acceptable.

10.1.2.7 Low Steam Generator Level

The low steam generator water level trip is required for the following events to help prevent exceeding the RCS design pressure due to a loss of heat sink:

1. Steam system piping failures,
2. Feedwater system pipe breaks,
3. Inadvertent opening of a steam generator atmospheric dump valve,
4. Loss of normal feedwater and
5. Asymmetric loss of feedwater.

The low steam generator water level trip ensures that the DNBR, kW/ft, and RCS pressure safety limits are maintained during normal operations and AOOs and, in conjunction with the ESFAS, the consequences of the steam and feedwater pipe break accidents will be acceptable.

10.1.2.8 Low Steam Generator Pressure

The low steam generator pressure trip provides protection against an excessive rate of heat extraction from the steam generators, which would result in a rapid uncontrolled cool down of the RCS. This trip is needed to shutdown the reactor and assist the ESFAS in the event of a main steam line break.

10.1.2.9 High Containment Pressure

The high containment pressure trip prevents exceeding the containment design pressure following certain loss of coolant accidents, steam line breaks, or feedwater line breaks. It assures a reactor trip prior to, or in conjunction with, accidents, thus assisting the ESFAS.

10.1.2.10 Loss of Load

The loss of load trip is anticipatory for the loss of heat removal capacities of the secondary system following a turbine trip. The loss of load trip prevents lifting of the pressurizer safety valves, PORVs, and the steam safety valves in the event of a turbine generator trip. Thus the trip minimizes the large upsets in RCS pressure and temperature by shutting down the reactor well before the high pressurizer trip set point is reached. Table 10.1-1 summarizes the purposes of all reactor trips.

10.1.3 System Description

As shown in Figure 10.1-1, each RPS channel receives independent inputs of safety related parameters. In each channel, the input signal is compared with its appropriate set point in a bistable. If the parameter is at set point, the bistable de-energizes. When the bistable de-energizes, a signal (in the form of an open relay contact) is sent to the logic matrices. Six (6) logic matrices are required to account for all possible combinations of two (2) out of four (4) channels (AB, AC, AD, BC, BD, and CD).

The logic matrix decides if the two (2) out of four (4) logic for any input parameter is satisfied and, if so, de-energizes its logic matrix relays. When the logic matrix relays de-energize, series contacts in the power supply to the RTB control relays open, resulting in the relays de-energizing.

Two events occur when the RTB control relays de-energize. First, contacts in the RTB's under voltage (UV) coil open, de-energizing the UV coil and opening the RTB. Second, contacts in the RTB's shunt trip coil close, energizing the shunt trip coil. When the shunt trip energizes, the RTB opens. This action is redundant to the opening of the breaker by the under-voltage coil. When the RTBs open, the coils of the CEA magnetic jack de-energize and the CEAs shutdown the reactor.

A few points should be added to the above discussion. First, the two (2) out of four (4) logic must exist for the same input parameter before a reactor trip will occur. The term coincidence is used to describe this feature. For example, at least two (2) pressurizer pressure transmitters must sense that pressurizer pressure is at or below set point before a reactor trip will occur. One (1) low pressurizer pressure input combined with any other input parameter reaching set point will not trip the reactor. Next, each RTB control relay controls two (2) RTBs. Control relay K1 controls breakers 1 and 5, control relay K2 controls breakers 2 and 6, control relay K3 controls breakers 3 and 7, and control relay K4 control relay controls breakers 4 and 8. Finally, as a minimum, one pair of circuit breakers in each of the supplies must open to de-energize all CEAs. This is called a one (1) out of two (2) logic taken twice. Table 10.1-2 provides a listing of possible reactor trip combinations.

TABLE 10.1-2
Reactor Trip Combinations

Breakers		Breakers
1-5	and	4-8
1-5	and	3-7
2-6	and	4-8
2-6	and	3-7

10.1.4 Component Description

10.1.4.1 Reactor Protection System Sensors

Criterion 24 of 10 CFR 50 requires separation between protection and control systems to prevent a control system failure from effecting the operability of the RPS. Combustion Engineering satisfies this requirement by the use of different detectors for protection systems and control systems. There are no shared inputs between the two electronic systems. In addition, there are four (4) sets of input parameters, one (1) set for each RPS channel. The output of the RPS sensors is supplied to the bistable relay cards in the RPS cabinets.

10.1.4.2 Bistable Trip Unit

The bistable trip unit (Figure 10.1-2) is used to compare the RPS input parameter with the pre-trip and trip set points and to generate pre-trip and/or trip signals if the pre-trip and trip comparators sense that the input signal equals the set point. There is a bistable trip unit for every trip in each RPS channel. Each bistable trip unit contains seven (7) relays that are maintained in an energized condition by the comparators as long as the input parameter is not at set point. When the parameter equals the set point the comparator output drops to zero and the relays de-energize.

Five (5) of the seven (7) relays are driven by the trip comparator. Three (3) relays are used in the two (2) out of four (4) logic matrices, and the other two (2) relays are used to provide reactor trip annunciation.

To illustrate the uses of the relays in the bistable trip unit, assume that the trip unit shown in Figure 10.1-2 is a channel "C" trip unit. The three (3) relays that are used in the two (2) out of four (4) trip logic operate contacts in the AC, BC, and the CD matrices. The trip indicator relay operates a trip indicator light on the bistable trip unit. The trip alarm relay operates contacts that activate control room annunciators and the computer sequence of events recorder. Bistable trip unit relays contain double coils. One coil operates contacts for logic matrix functions and the other functions as a test coil.

One of the bistable trip units, VOPT, has a variable set point that is supplied to the pre-trip and trip comparators. As shown in Figure 10.1-3, the VOPT set point is a function of the highest of nuclear power or ΔT power. The minimum set point for the VOPT is approximately 30%, and the maximum set point is 106.5%. Between these extremes, the set point is manually maintained at 10% above existing power. Set point adjustment is accomplished by four (4) push buttons (one for each RPS channel) located on the main control board.

The manual reset feature is illustrated by the following example. Assume that the plant is operating at 20% power with the VOPT set point at 30% and it is desired to escalate power to 100%. When power reaches 26%, a VOPT pre-trip is generated by the bistable trip unit. When the annunciator alarms the operator presses the push buttons to reset the VOPT setpoint to 40% and the pre-trip set point to 36%. As the power escalation continues, another pre-trip alarm is generated at 36% and the operator presses the push buttons to reset the VOPT set point to 50% and the pre-trip set point to 46%. These actions continue until the VOPT set point has been increased to 106.5%. When power is decreased, the set point automatically tracks downward with the set point remaining about 10% above the existing power.

10.1.4.3 Auxiliary Trip Units

The LPD trip and the loss of load trip are implemented by auxiliary trip units instead of bistable trip units. An auxiliary trip unit (Figure 10.1-4) is identical to a bistable trip unit with the exception that the relays are maintained in an energized condition by a normally closed contact. When a pre-trip or trip condition is sensed the contact opens and the relays de-energize. The relay outputs of the auxiliary trip unit are identical to the relay outputs of the bistable trip unit. The auxiliary trip unit relays and the bistable trip unit relays contain double coils, one coil that operates contacts for logic matrix functions and a test coil.

10.1.4.4 Logic Matrices

The logic matrices (Figure 10.1-5) consist of a series-parallel contact network and four (4) logic matrix relays to determine if the two (2) out of four (4) coincidence trip logic has been satisfied.

During normal operation, all matrix contacts are closed and the four (4) logic matrix relays are energized. To generate a reactor trip, two (2) parallel contacts must open. When the contacts open, the logic matrix relays de-energize and operate contacts that will open the RTBs. Each logic matrix is powered by redundant dc power supplies. Each of the power supplies is powered from a inverter supplied 120 Vac bus.

To illustrate the operation of the logic matrix, assume that the variable overpower as sensed by the "A" channel reaches the trip set point. When the trip set point is reached, the comparator in the variable overpower bistable trip unit de-energizes its three (3) trip relays. The de-energizing of the bistable trip relays opens the variable overpower contacts in the AB, AC, and AD matrices and closes a contact in series with the lamp located on the front of the bistable trip unit. All three (3) lamps on the "A" channel variable overpower bistable trip unit will be energized.

As shown in Figure 10.1-5, power will be supplied to logic matrix relays AB3 and AB4 from power supply 6 (PS6) through the closed B trip relay contacts, maintaining these relays energized. Current will travel from power supply 5 (PS5) through logic matrix relays AB1 and AB2, up through the closed "A" trip relay contacts until it reaches the open VOPT contact. Since current cannot flow through the open contact, current will flow through the closed "B" VOPT contact and back to power supply 5. Logic matrix relays AB1 and AB2 will be energized by this current flow.

Now assume that the "B" linear power channel also senses an overpower condition. The"B" channel VOPT bistable trip unit comparator's output will drop to zero and the three (3) trip relays will de-energize. When the relays de-energize, their associated contacts will open in the AB, BC, and BD matrices. When the "B" VOPT contact opens in the AB matrix (Figure 10.1-5), current flow from PS6 can no longer maintain logic matrix relays AB3 and AB4 energized. Likewise, the opening of the "B" VOPT contact prevents current from PS5 from flowing through logic matrix relays AB1 and AB2, and the relays de-energize. When the relays de-energize, a series contact in each of the four (4) RTBs control relay circuit opens. The opening of these contacts results in the opening of the RTBs.

As shown in figure 10.1-8, each logic matrix relay contains two (2) coils. One (1) of the coils is used for testing, and the other coil operates contacts in the RTB control relay circuitry.

10.1.4.5 Circuit Breaker Control Relays

There are four (4) RTB control relays, each control relay operates contacts in two (2) RTBs. Each control relay circuit contains six (6) series contacts, one (1) contact operated by a logic matrix relay from each of the six (6) logic matrices. For example, the RTB control relay K1 circuit (Figure 10.1-1) contains the AB1, AC1, AD1, BC1, BD1, and CD1 contacts. Opening any one of the series logic matrix relay contacts de-energizes the RTB control relay and two (2) RTBs will open. The RTB control relay circuitry is also called a trip path. A status panel above the RPS cabinets provides indication of trip path and RTB status.

10.1.4.6 Reactor Trip Circuit Breakers and CEA Power Supplies

The coils on the CEA magnetic jack assembly are supplied from two motor-generator (MG) sets (Figure 10.1-6). The MG set motors are powered from non-vital 480 Vac power. The MG set generator has an output of 240 Vac, 60 hz, 3 phase power. Either MG set is capable of providing 100% of the required CEA power; however, both MG sets are normally in service. Power from the MG sets is routed through the MG set output breakers to the CEAs via the RTBs. The MG output breakers are used to synchronize the generators and do not receive a trip signal from the RPS.

Nine (9) RTBs control the MG set power supply to the CEAs. As previously discussed, eight (8) of these breakers (numbers one through eight) are controlled by the trip path relays. Number nine RTB is installed to maintain MG set synchronization regardless of the order of closure of the RTBs. Number nine circuit breaker is not controlled by the RPS.

Under voltage coils monitor the CEA power supply. Should a reactor trip occur, the under voltage coils sense the decrease in supply voltage and provide signals to trip the turbine.

Figure 10.1-7 illustrates the mechanical operation of a typical RTB. During normal operations, the RTBs are closed supplying power to the CEAs. The circuit breaker under voltage (UV) coil (#3) is energized and holding the under voltage trip lever (#4). The power to keep the under voltage coil energized is controlled by the RPS.

When a trip signal is sensed through the appropriate logic (2/4), the RPS de-energizes the UV coil (#3) which releases the UV trip lever (#4). The UV trip lever causes the main trip shaft (#6) to rotate counterclockwise. When the main trip shaft rotates, the trip latch (#2) is released allowing the stored energy device (#1) to open the RTB (#7). Of course, opening of the RTBs removes power from the drive mechanisms allowing the CEAs to drop into the core.

The use of the under voltage coil to trip the reactor provides a fail safe feature for the RPS. If a loss of power to the RPS should occur, the UV coils would de-energize and the RTBs would open as described above.

10.1.5 Integrated Operations

The discussion in the following sections (10.1.5.1 and 10.5.1.2) refers to figure 10.1-8 (Reactor Protection System Functional Diagram). This figure, shown de-energized, complies with industry standards and is drawn in the same general format as the process and instrument diagrams found in the plant. All relay contacts that close when a relay is energized, "a" contacts, appear as open contacts, and any relay contacts that open when a relay is energized, "b" contacts, are shown closed. Therefore, if the text states that a contact is closed, it is referring to an energized circuit although the figure shows that same contact as open.

10.1.5.1 Reactor Trip

Using figure 10.1-8, assume that a slow depressurization of one steam generator occurs. This transient will generate a trip signal actuated by either a high containment building pressure or a low steam generator pressure and is chosen to demonstrate the two (2) out of four (4) coincidence trip logic.

As the steam generator depressurizes, steam is released into the containment building and the pressure inside the containment building will increase. When containment building pressure reaches the trip set point, a reactor trip signal is generated. Assume that the "A" RPS channel is the first protective channel to sense the high containment building pressure.

Remember, if a process parameter equals or exceeds a bistable trip set point, the bistable trip unit de-energizes three (3) trip relays. Each trip relay provides an input into a separate logic matrix. In this case when the pressure inside the containment building reaches or exceeds 2.8 psig. The auxiliary bistable trip unit de-energizes three (3) trip relays.

When these trip relays de-energize, their associated logic matrix contacts open. The contacts that open are as follows:

a. The A9-1 contact in the AB matrix
b. The A9-2 contact in the AC matrix
c. The A9-3 contact in the AD matrix

When the trip contacts in the matrix logic open, their associated trip relay lamps energize. Therefore, three (3) trip relay lights energize on the auxiliary bistable trip unit. Although one contact is open in each of the three (3) logic matrices, the logic matrix relays remain energized and the reactor trip circuit breakers remain closed.

Tracing the electrical current flow path from the power supplies, PS-5 and PS-6, through the AB logic matrix, illustrates why a reactor trip has not occurred.

Power supply PS-6 keeps logic matrix relays' AB-3 and AB-4 energized via the following electrical flow path. Current flows from the PS-6 power supply through logic matrix relays AB-3 and AB-4 to the contact string containing the

B1-1 through the B10-1 contacts. Presently all the series contacts on the "B" side of this logic matrix are closed. Therefore, there is not a break in continuity of this circuit and current is allowed to flow back to the positive side of the PS-6 power source.

Meanwhile, power supply PS-5 keeps logic matrix relays' AB-1 and AB-2 energized via the following electrical flow path. Current flows from the PS-5 power supply through logic matrix relays AB-1 and AB-2 to the contact string containing the A1-1 through the A10-1 contacts. The current flows upward through the closed A10-1 contact and then encounters the A9-1 contact that is open. The current flow back to the positive side of the PS-5 power source is broken, and without an alternate route for the current to flow to the logic matrix relays, AB-1 and AB-2 would de-energize. However, a cross-connect line between contacts A10-1 and A9-1 allows current flow to the "B" series contacts. With this configuration a current path is available and the PS-5 power source keeps the AB-1 and AB-2 relays energized. Similar power supply paths exist for the AC and the AD logic matrices.

Assume that the "C" channel steam generator pressure transmitter senses a steam generator low pressure condition before a second high containment building pressure condition is sensed. When the "C" low steam generator pressure bistable strip unit de-energizes; its three (3) trip relays de-energize and open the following contacts:

1. C5-1 in the AC matrix
2. C5-2 in the BC matrix
3. C5-3 in the CD matrix

As previously discussed, the associated trip relay lamps on the low steam generator pressure bistable trip unit are energized. In addition, the pre-trip and trip lamps are also energized. The logic matrix for the BC and the CD matrices operate the same as the sequence described for logic matrix AB. However, two contacts are now open in the AC logic matrix A9-2 and C5-1.

Tracing the power supplies, PS-7 and PS-8 through the AC logic matrix, illustrates why a reactor trip has not occurred.

Current flows from the PS-7 power supply through the logic matrix relays AC-1 and AC-2 to the contact string containing the A1-2 through the A10-2 contacts. The current flows upward through the closed A10-2 contact and then encounters the A9-2 contact that is open and blocks the current flow. However, a cross-connect line between contacts A10-2 and A9-2 allows current flow to the "C" series contact string until it encounters open contact C5-1. This open contact prevents current flow and would de-energize the logic relays AC-1 and AC-2 except that between contacts C6-1 and C5-1 a cross-connect exists that allows the electrical current to flow back to the "A" contacts in this string)A5-2 through A1-2) are closed. This provides a current path back to the PS-7 power source and keeps the AC-1 and AC-2 relays energized.

Power supply PS-8 keeps the AC-3 and the AC-4 relays energized with the following current flow path. The electrical current flows through these relays (AC-3 and AC-4), up the "C" series contacts until it reaches the open C5-1 contact. Similar to the previous paragraph, the current flows through the cross-connect over to the "A" series contacts and continues upward and is routed back to the PS-8 power supply.

The logic matrix relays in the AC logic matrix remain energized and the reactor does not trip. As illustrated by this example, any number of trip inputs may occur within a logic matrix, and since two contacts in parallel are not de-energized at the same time, a reactor trip will not occur.

As the pressure within the affected steam generator continues to decrease, assume that the "D" channel senses a low steam generator pressure. The "D" channel steam generator low pressure bistable trip unit opens contacts in the following matrices:

1. D5-1 in the AD matrix
2. D5-2 in the BD matrix
3. D5-3 in the CD matrix

From a practical standpoint, although three (3) matrices are affected, the important action takes place in the CD logic matrix. When the D5-3 contact opens, two parallel contacts are open in the CD matrix (contact C5-3 was opened earlier). With two parallel contacts open current flow through both contact strings of this circuit is interrupted and the following logic relays de-energize; CD-1, CD-2, CD-3, and CD-4. When these logic matrix relays de-energize, their associated contacts open.

In the lower left portion of figure 10.1-8, a transformer powered from Vital Bus #1 is shown. Notice: directly below and to the left of the transformer is a series of contacts. When the logic matrix relay CD-1 de-energizes, its associated contact (CD-1) opens. This action breaks the continuity of this circuit de-energizing relay K1. When this relay de-energizes, it removes power from the under voltage coils and energizes the shunt trip coils in reactor trip breakers (TCB-1 and TCB-5).

This action, by itself, will not generate a reactor trip because reactor trip breaker pairs (TCB-4 and TCB-8) and (TCB-3 and TCB-7) are still closed. However, as previously stated, contacts' CD-3 and CD-4 are open. Examining the action caused by just one of these contacts (CD-4) shows that, if the CD-4 contact opens, relay K4 de-energizes. When this relay de-energizes, it de-energizes the under voltage coils and energizes the shunt trip coils for reactor trip breakers TCB-4 and TCB-8. Recall that one set of trip breakers, TCB-1 and TCB-5, is already open. Therefore, when these breakers open, all power is lost to the control element drive mechanisms and the control element assemblies fall into the core shutting down the reactor.

As described in Section 10.1.3, only one pair of breakers in each side of the CEDM power supplies must open to cause a reactor trip. In this discussion the pairing of breakers selected was sufficient to trip the reactor.

A subtle thing also occurs with the RPS trip relay lamps during certain events. The trip relay lamps receive power from the same source that supplies the logic matrix relays. It illuminates when a "b" contact closes. This action occurs simultaneously when its associated logic contact opens. If the contacts located above the tripped contacts remain closed, continuity of the circuit is maintained and the trip relay lamps remain lit. Therefore, in this example, when contacts' C5-3 and D5-3 open, power is lost to the high containment trip relay lamps (D9-3). Overall, only the lowest numbered trip relay lamps remain energized following a reactor trip. The result of this action means that a reactor trip "first out" cannot be determined from the Reactor Protection System front panels.

10.1.5.2 Loss of 120 Vac Bus

The design of the RPS is such that the loss of a single 120 Vac vital bus should neither prevent nor cause a reactor trip. Referring to the lower left hand section of figure 10.1-8, assume that a loss of vital bus #1 occurs.

After losing this power source, the K1 relay de-energizes. De-energizing the K1 relay opens the contacts to the under voltage coils and closes the contacts that supply power to the shunt trip coils for reactor trip breakers TCB-1 and TCB-5. Either of these actions opens this pair of reactor trip breakers. A reactor trip does not occur because the reactor trip breaker pairs (TCB-4 and TCB-8) and TCB-3 and TCB-7) are unaffected by the loss of vital bus #1 and remain closed.

Losing this power source (vital bus #1) also affects the following dc power supplies; PS-5, PS-7, and PS-9. Tracing the electrical circuit of the A-B logic matrix, notice that the PS-5 power supply normally keeps logic matrix relays AB-1 and AB-2 energized. However, in this example, this dc power source is lost and these relays de-energize. Once these relays de-energize, their associated contacts AB-1 and AB-2 open. Losing the AB-1 relay in this example has no impact because the K1 relay was lost as a direct result of de-energizing vital bus #1. However, opening the AB-2 contact de-energizes reactor trip relay K2. De-energizing the K2 relay has the similar affect as de-energizing the K1 relay except in this instance reactor trip breakers TCB-2 and TCB-6 open. Opening these two breakers has no additional affect upon the system because these breakers are in series with the previously opened reactor trip breakers.

Despite the electrical fault: a loss of an individual dc power supply, or the loss of an entire vital instrument bus, a reactor trip will not occur. In addition to losing one half (½) of the reactor trip breakers, the loss of power changes the trip logic for the logic matrices affected by that loss of power. For example, if the PS-5 power supply was lost, not only do the logic relays AB-1 and AB-2 de-energize, but all the contacts (AB-1 through A10-1) on the left side of the logic matrix open. Operating under these conditions, the logic matrix is aligned so if any single contact opens on the "B" side of the matrix (B1-1 through B10-1), continuity of the circuit is broken, and logic relays AB-3 and AB-4 de-energize. Therefore, with these conditions, a one-out-of-three (1/3) logic exists for the logic matrices affected by the power loss, that is, logic matrix AB, AC, and AD.

10.1.6 RPS Bypasses

10.1.6.1 Trip Channel Inhibit

The trip channel inhibit is provided to remove a trip channel from service during maintenance or testing. When the trip channel inhibit is in effect, the trip logic for that trip is changed to a two (2) out of three (3) logic. As an example, if the low steam generator level trip for "A" steam generator is inhibited in RPS channel "A", RPS channels "B", "C", and "D" will continue to provide steam generator low level trip capability. Any inhibit must be manually initiated and removed at the RPS cabinets.

To inhibit an individual trip function the key for that trip is inserted in the appropriate RPS channel and turned. When the inhibit key is turned contacts in parallel with the bistable trip relay in the logic matrices for the affected trip function are closed. This action inhibits the trip from that channel only.

The inhibit keys are administratively controlled such that no more than one key is available for each of the reactor trips. This RPS design would allow the same reactor trip function to be inhibited in multiple channels if multiple keys were available. Operationally, inhibiting more than one channel for a particular trip function is not allowed by technical specifications.

10.1.6.2 Automatic Bypasses

The operability of the high startup rate, LPD, and loss of load trips are power level dependent. Nuclear instrumentation system bistables provide interlock signals to activate/deactivate these trip functions. The high start-up rate is active when power is greater than or equal to 10^{-4}% (as sensed by wide range logarithmic power) and remains operable until power is greater than or equal to 15% (as sensed by the linear power range safety channel).

At power levels above 15%, feedback from the moderator temperature and doppler coefficients, along with the variable overpower trip provide protection against reactivity excursions and protection by the high startup rate trip is not required. Below 10^{-4}% power, poor counting statistics can lead to erroneous indications; therefore, the high startup rate trip function is automatically bypassed.

The LPD and loss of load trips are automatically bypassed until power, as sensed by the linear power range safety channels, exceeds 15%. Below 15% power, no values of LPD will result in violation of kW/ft limits; therefore, the LPD trip can be safely bypassed.

The 10^{-4}% and 15% power signals used for trip bypassing are channelized. In order to bypass the "A" RPS loss of load trip, power must be less than 15% as sensed by the linear power range safety channel located in the "A" RPS cabinet. Therefore, to ensure that a loss of load trip will not occur, three (3) of the four (4) linear power range safety channels must sense that power is less than or equal to 15%. The above discussion is also applicable to LPD, and if the 10^{-4}% limit is added, the statements apply to all automatically bypassed trips.

10.1.6.3 Zero Power Mode Bypass

The RPS zero power mode bypass feature allows the TMLP and the low RCS flow trips to be bypassed to permit CEA operation during shutdown and cool down evolutions. The zero power mode bypass is manually actuated when it is desired to cool down with the shutdown CEAs withdrawn or when CEA testing is to be performed during shutdown. Cooling down with the shutdown groups withdrawn provides a method of quickly adding negative reactivity to the core should the need arise.

Two conditions must be satisfied for each RPS channel zero power mode bypass:

1. Power, as sensed by the wide range logarithmic power channel must be less than or equal to 10^{-4}%, and

2. A key lock switch, located on the RPS cabinet, must be turned to the bypass position.

When these conditions are satisfied, the bistable trip relays for the TMLP and low RCS flow trip units remain energized by applying a fixed voltage to the relay amplifiers. In addition to blocking the trip functions, the zero power mode bypass also prevents the selection of ΔT power by the TMLP power calculation. An indicating light on the RPS cabinet, labeled ΔT power block is energized to inform the operating staff of this condition. When power is escalated to $>10^{-4}$%, the zero power mode bypass and the ΔT power block are automatically removed.

10.1.6.4 Low Steam Generator Pressure Bypass

Provisions are made to bypass steam generator pressure during a cool down so that a reactor trip will not occur. Two conditions must be satisfied to bypass the low steam generator pressure reactor trip. First, steam generator pressure must be less than or equal to 785 psia. Next, a key operated bypass switch must be positioned to the bypass position on the RPS. With this trip bypassed, a cool down can proceed without the actuation of a reactor trip. If steam generator pressure exceeds 785 psia, then the low steam generator pressure bypass is automatically removed.

10.1.7 RPS Interfaces

10.1.7.1 CEA Withdrawal Prohibit Interlocks

CEA withdrawal prohibit (CWP) signals are generated by VOPT, high start-up rate, and TMLP pre-trips. The CWP interlock prevents manual or automatic CEA withdrawal causing a greater degradation of these parameters. CWPs have a two (2) out of four (4) logic for each parameter. The TMLP CWP is bypassed if power is less than or equal to 10^{-4}% power.

10.1.7.2 PORV Actuation

The power operated relief valves (PORVs) are opened in conjunction with a high pressurizer pressure trip. Trip unit relays in the high pressurizer pressure trip bistables have contacts in a two (2) out of four (4) coincidence logic that actuate the PORVs. When testing a high pressurizer pressure trip channel, the trip bypass switch energizes a relay whose contacts parallel the trip unit relay and reduces the actuation logic to a two (2) out of three (3).

10.1.8 RPS Testing

Provisions are made to permit periodic testing of the complete RPS with the reactor at power. These tests cover the trip actions from sensor input, bistable trip relay actuation, logic matrix relay actuation, trip path relay actuation, and finally the opening of the RTBs. These individual tests are described below.

10.1.8.1 Sensor Checks

During reactor operation, the sensors that provide inputs to the RPS are checked by comparing the outputs of all four (4) instruments that measure the same parameter. This is called a channel check. Plant technical specifications require the performance of this check on a periodic basis.

During extended shutdown periods or refueling shutdowns, the sensors are checked and calibrated against known standards.

10.1.8.2 Trip Bistable Tests

Testing of trip bistables is accomplished by manually varying the input signal to the trip comparator (Figure 10.1-2) up or down to the trip set point. Only one bistable is tested at a time and observing the trip action as evidenced by the logic matrix lamps at the bistable trip unit.

Varying the input signal is accomplished by the trip test circuit that consists of a digital voltmeter, test selector switches, and a potentiometer. The bistable to be tested is selected and the test signal is applied. The digital voltmeter may be used to determine the trip set point.

Since the bistable relays are de-energized during the test, the trip function is placed in trip channel inhibit. This test is performed in accordance with technical specifications and is called a channel functional test.

10.1.8.3 Logic Matrix Test

This test is performed to verify proper operation of the six (6) logic matrices. As shown in Figure 10.1-8, the test power supply supplies power to the hold coils of the trip bistable relays (the bistable trip relay has two coils, one that is powered from the comparator, and one powered from the test circuit).

Actuation of the push button applies a test voltage to the test system hold coils of the double coil matrix relays. This voltage will provide the power necessary to hold the relays in their energized position when actuation of the bistable trip relay contacts in the matrix ladder being tested causes the primary matrix relay coils to de-energize.

The logic matrix to be tested is selected using the system channel trip select switch located at the RPS channel cabinets. Then while depressing the matrix hold push button, rotation of the channel trip select switch will release only those bistable trip relays that have operating contacts in the logic matrix under test.

The channel trip select switch applies a test voltage of opposite polarity to the bistable trip relay test coils so that the magnetic flux generated by these coils opposes that of the primary coil of the relay. The resulting flux will be zero, and the relays will release.

Trip action can be observed by illumination of the trip relay indicators located on the front panel and by loss of voltage to the four matrix relays, which is indicated by extinguishing the indicator lights connected across each matrix relay coil.

During this test, the matrix relay hold lights will remain on, indicating that a test voltage has been applied to the holding coils of the logic matrix module under test.

The test is repeated for all six (6) matrices and for each actuation signal. This test will verify that the logic matrix relays will de-energize if the matrix continuity is lost. The opening of the matrix relays is tested in the trip path tests, and is a part of the channel functional test.

10.1.8.4 Trip Path/Circuit Breaker Tests

Each trip path is tested individually by depressing a matrix hold push button (holding the matrix relays), selecting any trip position on the channel trip select switch (opening the matrix), and selecting a matrix relay on the matrix relay trip select switch (de-energizing one of the four matrix relays), causes two (2) RTBs to open. CEDMs remain energized via the other RTBs (Figure 10.1-6).

The drop out lamps shown on Figure 10.1-8 are used to provide additional verification that the matrix relay has been de-energized, (the AB-1 matrix relay contact energizes the drop out lamp). Proper operation of the actual trip path matrix relay contacts is verified by the trip path lamp located on the trip status panel.

Proper operation of all coils and contacts is verified by lights on a trip status panel. Final proof of opening of the RTBs is the lack of indicated current through the trip breakers.

The matrix relay trip select switch is turned to the next position, re-energizing the tested matrix relay and allowing the RTBs to be manually reset.

This sequence is repeated for the other three (3) trip paths from the selected matrix. Following this the entire sequence is repeated for the remaining five (5) matrices. Upon completion all twenty four matrix relay contacts and all four (4) trip paths and breakers will have been tested. This test is also a part of the channel functional test.

10.1.8.5 Manual Trip Test

The manual trip feature is tested by depressing one (1) of the four (4) manual trip push buttons, observing a trip of two (2) RTBs, and resetting the breakers prior to depressing the next manual trip push button. This test is performed prior to a reactor startup, unless performed in the previous seven (7) days.

10.1.9 PRA Insights

The purpose of the RPS is to initiate reactor trips to prevent the plant from reaching a safety limit and initiate engineered safety features to mitigate the consequences of an accident. The major RPS PRA concern is an anticipated transient without scram (ATWS). According to the Calvert Cliff's PRA, the ATWS has a core melt frequency contribution of 33%. The dominant accident sequence assumes that a transient (loss of offsite power, loss of feedwater, turbine trip) starts with all the front line systems initially available and proceeds as follows:

1. A valid trip signal is received, and a failure of the reactor trip circuit breakers occurs.

2. The main feedwater pumps trip or runback to a low feedwater flow condition.

3. Primary system failure results due to an over pressure and subsequent core melt.

4. No credit is taken for operator initiation of feed and bleed core cooling, or tripping the reactor.

A failure of the RPS would allow the heat production in the core to continue, while the power conversion system would be removing heat at a reduced rate. The resulting imbalance between the energy removal rate (5%) and the energy production rate (100%) leads to the heatup of the RCS and an increase in system pressure. The magnitude of the pressure increase is determined by the initial power level, heat removal rate, and the net reactivity in the core. The moderator temperature coefficient determines the negative feedback between the temperature rise and resulting power decrease by decreasing the density, or voiding of the primary coolant.

Given that the peak pressure exceeds the service level (3200 psia) limit, various types of system damage have been postulated:

1. If the pressure should exceed 3500 psia, then the reactor vessel head could lift and likely fail to reseat completely.

2. The response of the steam generator tubes is uncertain at these differential pressure and a large number could potentially rupture.

3. Because there is insufficient analysis of the operability of check valves in the primary system for the pressures exceeding the service level limit, there is an assessment that the chemical and volume control and high pressure safety injection systems would be unavailable some significant fraction of the time due to check valves being forced shut and deformed to the point of inoperability. Thus, continued reactor cooling and long term recovery after the system has been over pressurized is questionable, and significant core damage could result from an initiating failure of the RPS.

The risk reduction factor for the RPS is 1.53, and the risk achievement factor is 11,539. The large risk achievement factor is due to the small failure probability of the RPS that is assumed in the PRA. As previously stated, no credit was given for operator actions mitigating this event. Calvert Cliffs has implemented an ATWS procedure which directs the operator to:

1. Trip the reactor manually,

2. Deenergize the motor generator sets (to the CEAs) and

3. Initiate emergency boration.

De-energizing the motor generator sets should bypass any actuation of control circuit failures and result in a successful trip. If done quickly enough, this could result in a reduction in any pressure transient. With appropriate operator training, it may be possible to mitigate this sequence.

The only other ways of reducing this sequence's frequency or mitigating the results appear to involve changes to the plant such as:

1. Reduce the number of transients,

2. Improve RPS reliability,

3. Qualify the RCS and valve operability at higher pressures,

4. Improved analysis to show peak pressure less than current prediction or

5. Change fuel loading so that a more negative MTC is obtained.

10CFR50.62 requires additional safety improvements in the design and operation of light water cooled nuclear powered reactors to minimize the probability of an ATWS event. The requirements are intended to reduce the likelihood of failure of the reactor trip systems to scram the reactor following an ATWS and reduce the consequences should failures occur. The requirements for pressurized water reactors are:

1. Additional equipment, independent of the reactor trip system, to automatically activate the auxiliary feedwater system and initiate a shutdown of the plant turbine under conditions indicative of an ATWS.

2. An additional scram system (all of those components of the reactor trip system exclusive of sensors, control element assemblies and their mechanisms) which also is independent of the reactor trip system. Calvert Cliffs has added a diverse scram system to comply with item 2 above. The system utilizes four pressurizer pressure channel instruments that interrupt the output of the CEDM MG sets when pressurizer pressure exceeds 2450 psia as sensed by at least two (2) of the four (4) transmitters.

10.1.10 Summary

The RPS functions to insure that the fuel cladding and RCS barriers remain intact during anticipated operational occurrences. In addition, the RPS aids the ESFAS in the mitigation of accidents by insuring the reactor is shutdown.

The RPS senses safety related parameters and generates a reactor trip signal if any parameter reaches set point. The RPS has four (4) separate channels and functions with a two (2) out of four (4) logic to trip the reactor. Eight (8) RTBs are controlled by the RPS. These breakers are arranged in two (2) parallel strings with each string consisting of four (4) breakers. The four (4) breakers are arranged in parallel pairs. The trip logic for the circuit breakers is a one (1) out of two (2) for each parallel string.

TABLE 10.1 REACTOR TRIP SUMMARY

TRIP	PRE-TRIP SET POINT	TRIP SET POINT	PURPOSE
1. Variable Overpower	104.5%	106.5%	Fuel cladding protection during rapid reactivity excursions
2. High SUR [1]	1.5 DPM	2.6 DPM	Startup Protection (backup to VOPT)
3. Low RCS Flow [2]	97%	95%	DNBR
4. Low SG Level	47%	37%	Heat Sink Protection
5. Low SG Pressure [5]	767 psia	703 psia	Ensures reactor shutdown in the event of a MSLB
6. High Pressurizer [4] Pressure	2350 psia	2400 psia	RCS Boundary Protection
7. Thermal Margin Low Pessure [2]	50 psia above setpoint	Variable	DNBR
8. Loss of Load [3]	No pre-trip	Turbine Trip	Prevents large RCS pressure upsets (lift of PORVs, safeties)
9. High Containment Pressure	No pre-trip	2.8 psia	Ensures reactor shutdown in events requiring safety injection
10. Local Power [3] Density (Axial Power Distribution)	Variable	Variable	kW/ft. (Prevent peak local power)

Notes
1. Trip is bypassed below 10^{-4}% and above 15%.
2. Trip is bypassed in zero power mode bypass.
3. Trip is bypassed below 15% power. Trip utilizes an auxiliary trip unit.
4. The pressurizer power operated relief valves are opened by the high pressurizer pressure trip.
5. Trip may be bypassed at 785 psia.

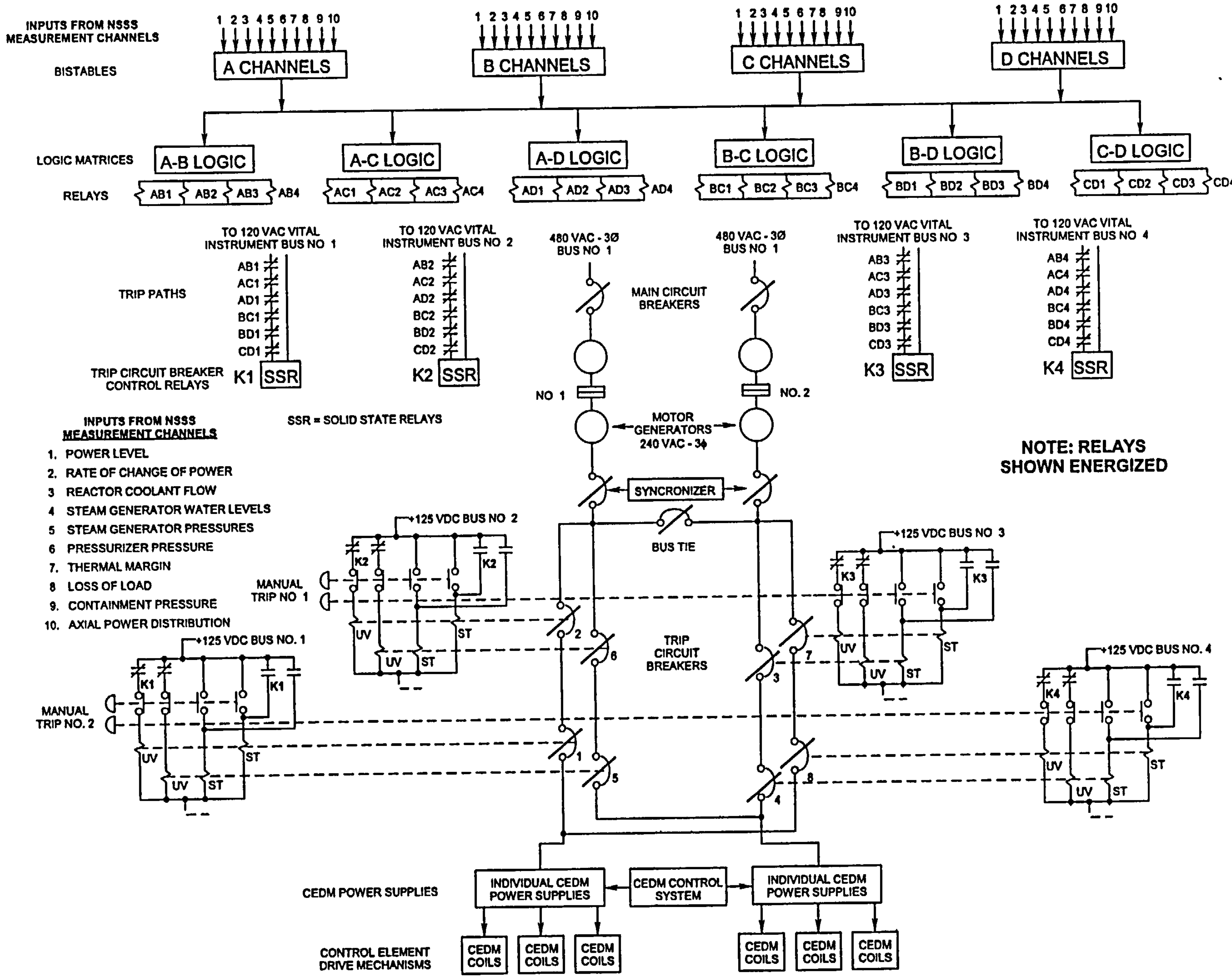

Figure 10.1-1 Simplified Reactor Protection System

1000-10

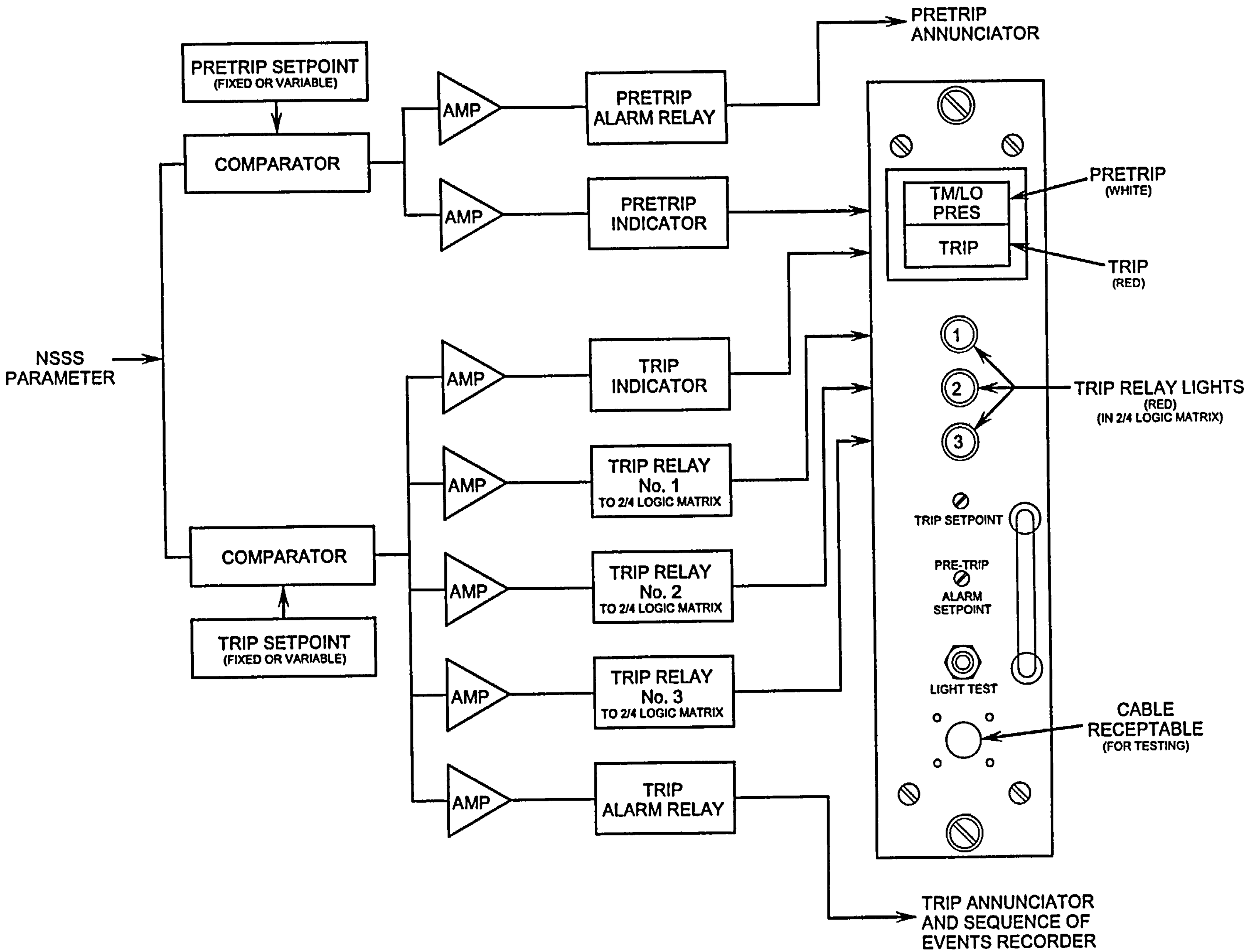

Figure 10.1-2 Bistable Trip Unit

1000-10

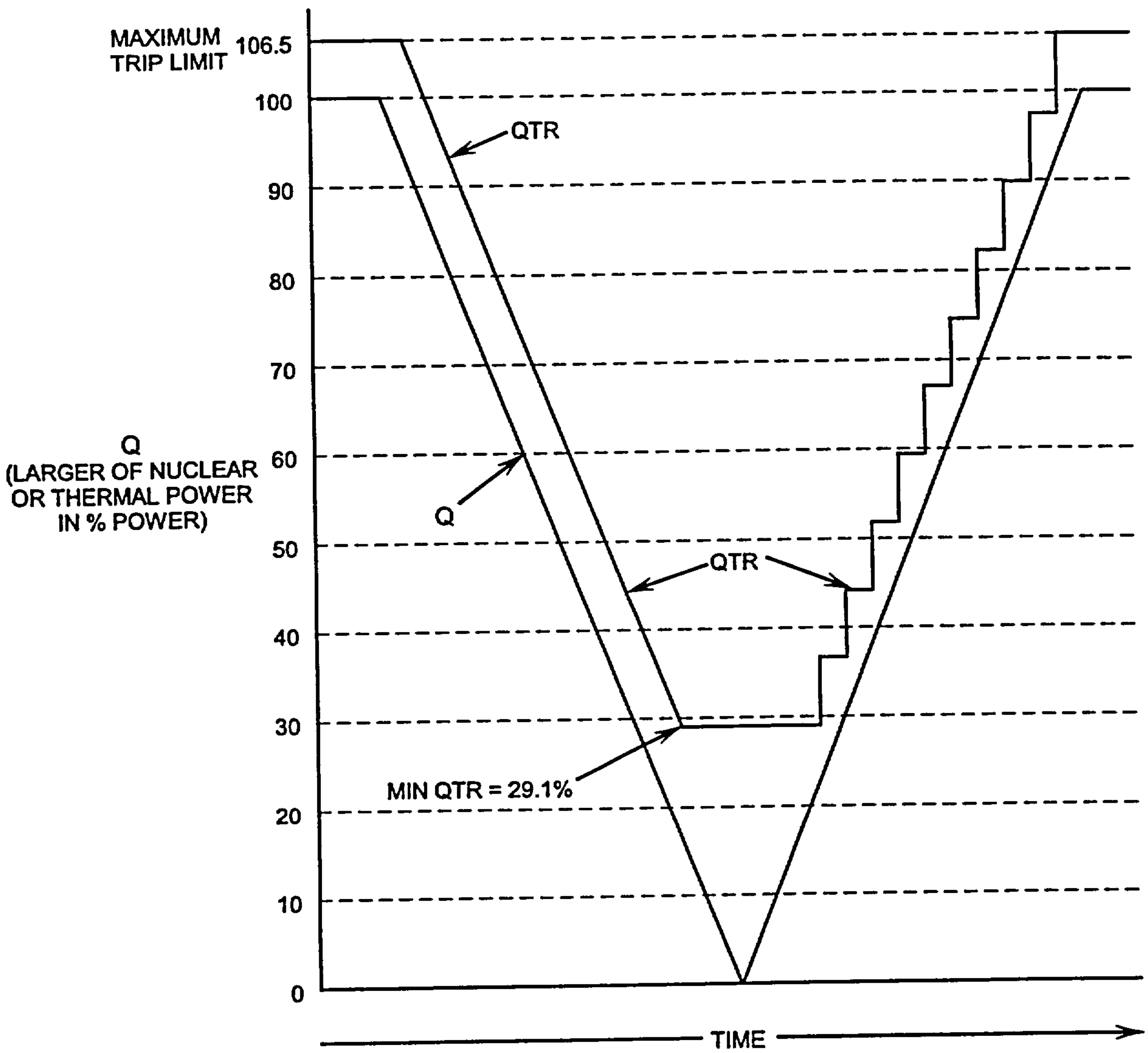

Figure 10.1-3 Variable High Power Trip Operation

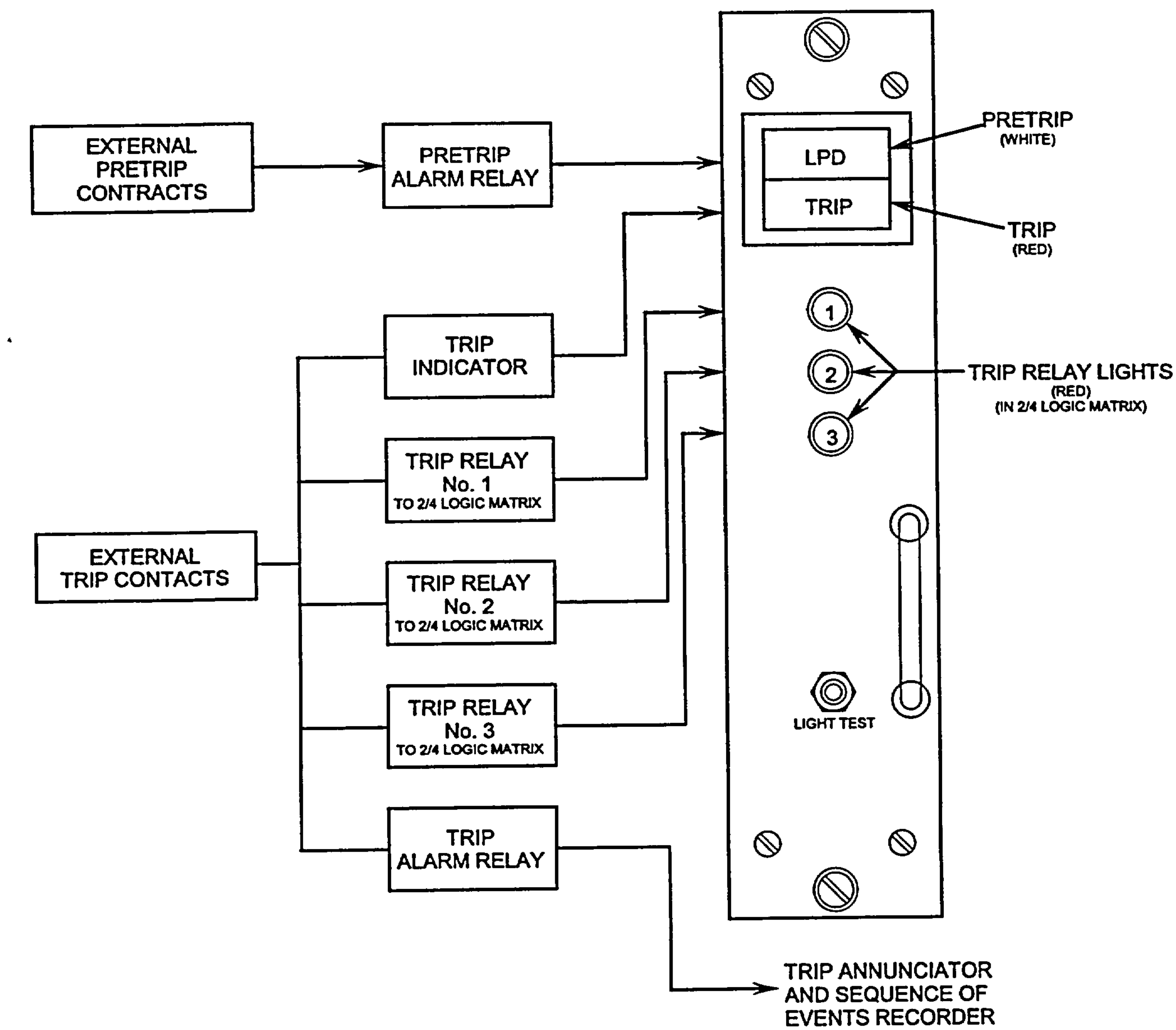

Figure 10.1-4 Auxiliary Trip Unit

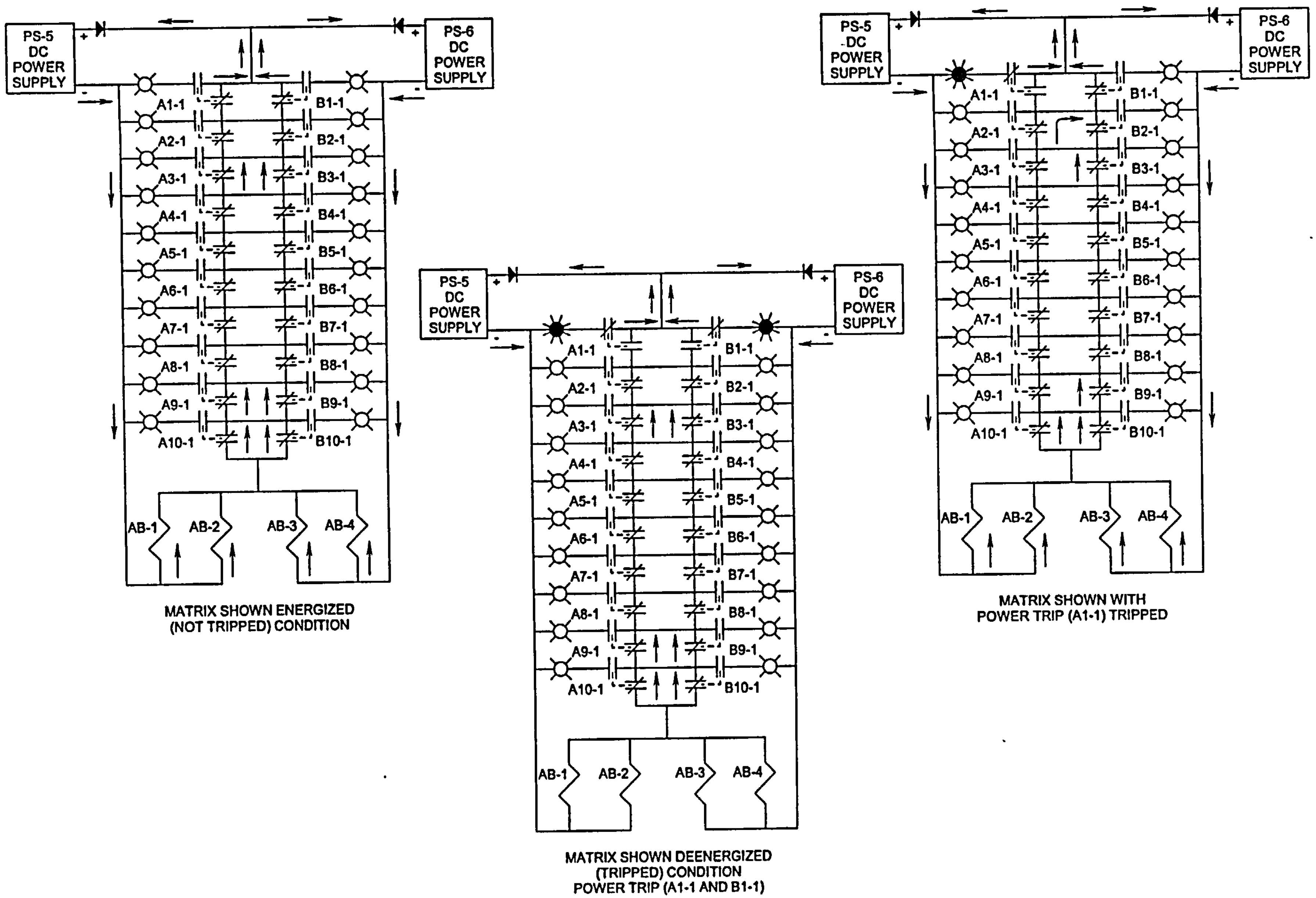

Figure 10 1-5 Coincidence Logic Matrix AB

1000-1C

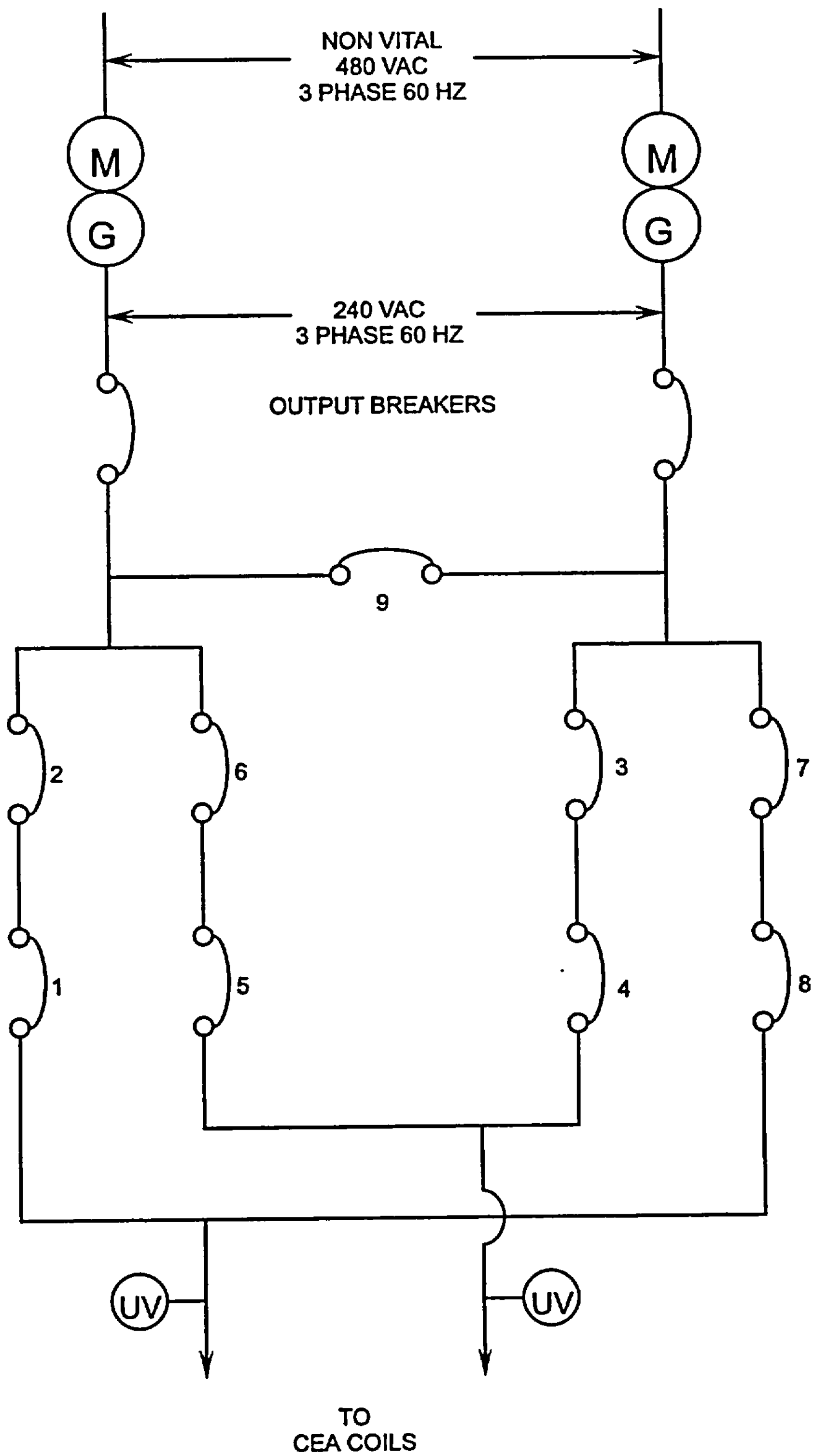

Figure 10.1-6 CEA Power Supply

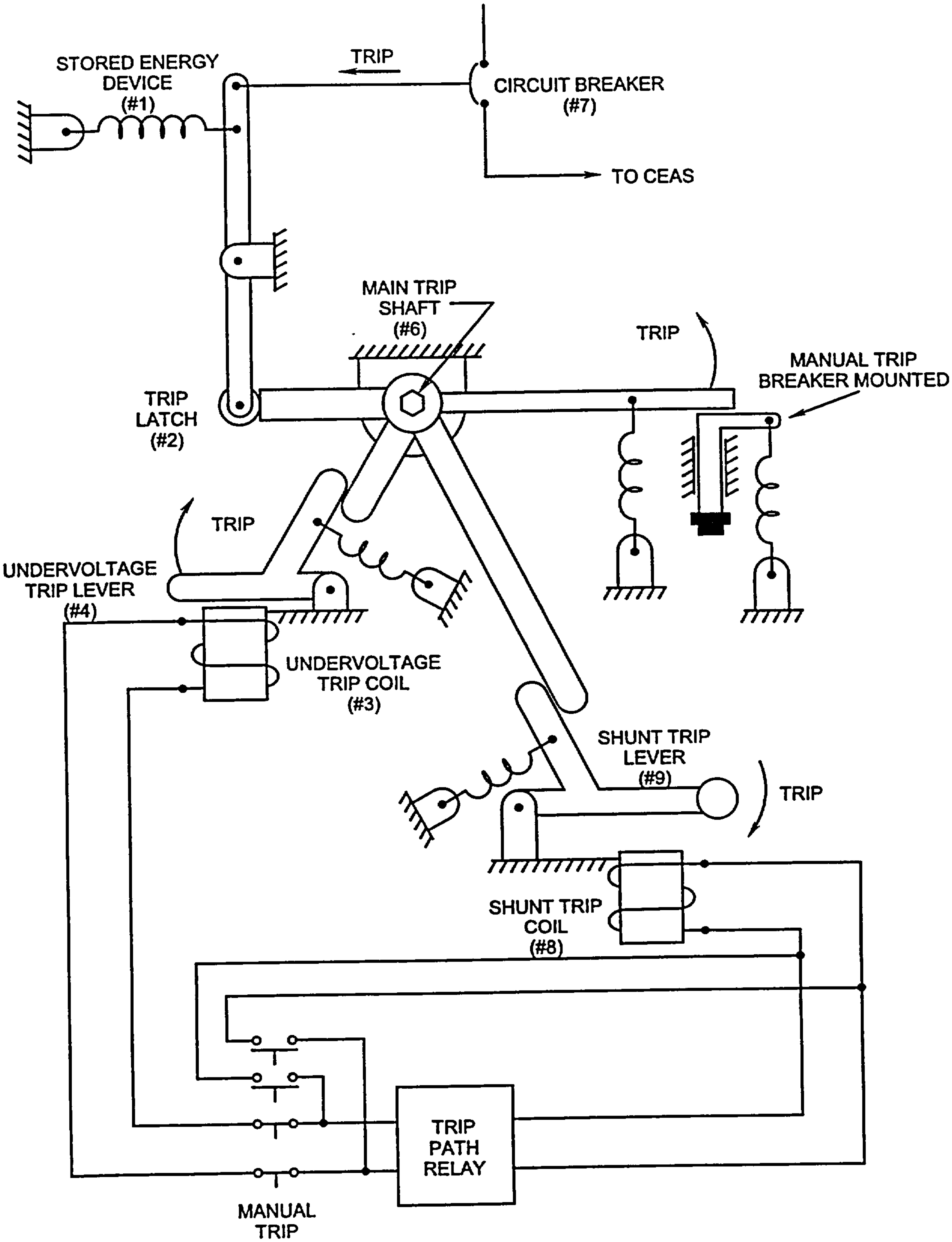

Figure 10.1-7 Reactor Trip Circuit Breaker

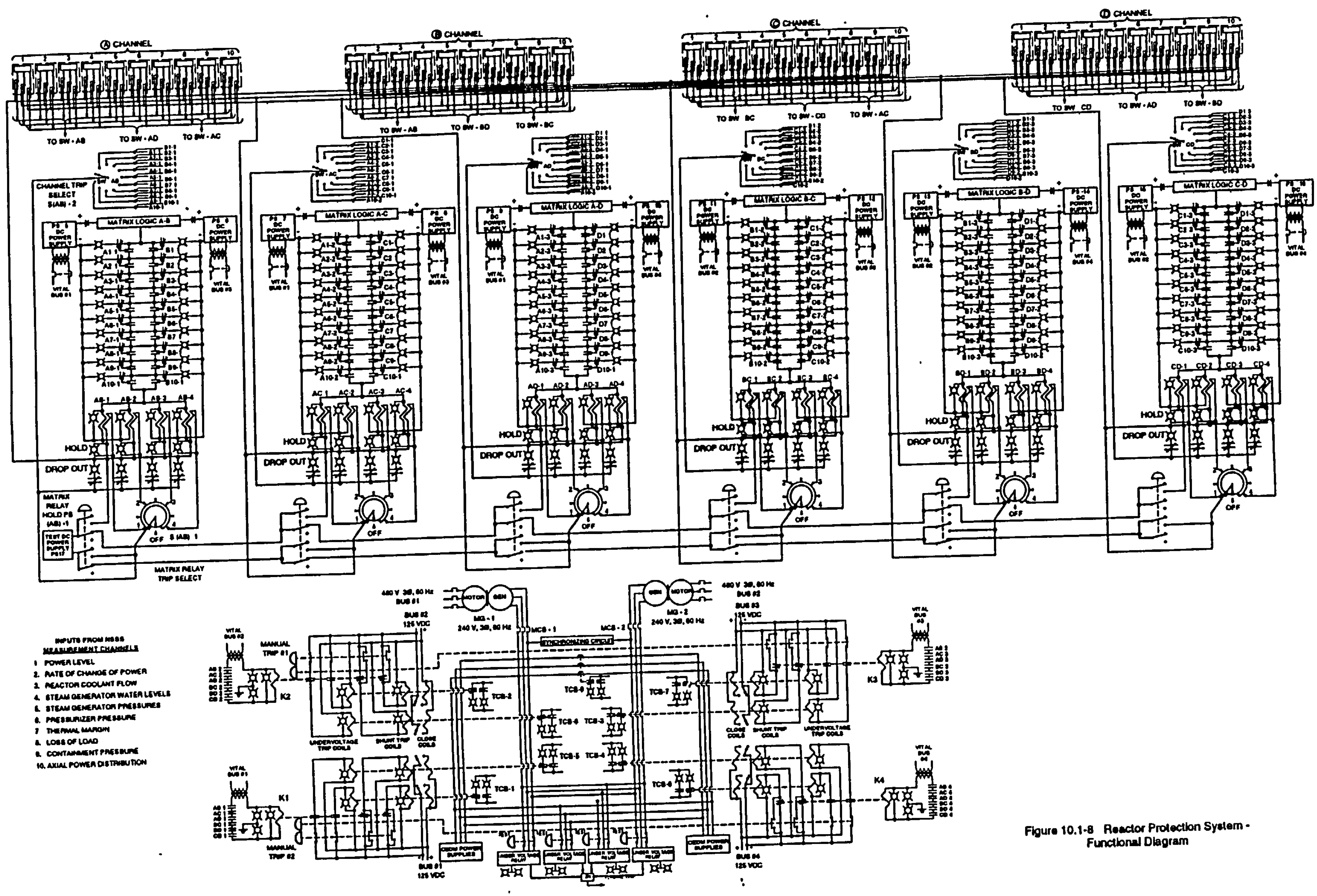

Figure 10.1-8 Reactor Protection System - Functional Diagram

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10.2 THERMAL MARGIN LOW PRESSURE AND LOCAL POWER DENSITY TRIPS

LIST OF FIGURES

10.2 THERMAL MARGIN LOW PRESSURE AND LOCAL POWER DENSITY TRIPS

Learning Objectives:

1. State the purposes of the thermal margin low pressure (TMLP) and local power density (LPD) trips.

2. List the inputs to the TMLP and LPD trips.

3. State the plant conditions used to determine when these trips are in effect.

10.2.1 Introduction

The TMLP trip and the LPD trip function to ensure that the specified acceptable fuel design limits (SAFDL) of departure from nucleate boiling (DNB) and linear power density (kW/ft) are not exceeded during anticipated operational occurrences (AOOs). The TMLP and LPD trips also help to ensure cladding integrity during upset conditions such as a complete loss of reactor coolant system (RCS) flow. In addition a TMLP trip will be generated if asymmetric steam generator conditions exist.

The TMLP trip receives inputs from:

1. RCS hot leg temperature,

2. RCS cold leg temperature,

3. Linear power range safety channel,

4. Pressurizer pressure,

5. Axial shape index (ASI),

6. RCS flow dependant selector switch (FDSS), and

7. Steam generator pressures.

The TMLP calculator combines all of these inputs and calculates an allowable operating pressure (set point). If the actual pressure in the RCS is less than or equal to the allowable operating pressure, a trip signal is generated.

The LPD trip receives inputs from both of the neutron detectors of the linear power safety channel and compares the reactor's actual ASI (internal tilt) with an allowable ASI generated by the LPD trip unit. If actual ASI exceeds allowable ASI, a trip signal is generated.

10.2.2 TMLP Calculator

As previously stated, the purpose of the TMLP trip is to prevent reactor operations with the departure from nucleate boiling ratio (DNBR) less than its design value. In addition this calculator will generate a reactor trip signal if asymmetric steam generator conditions exist.

An asymmetric steam generator is a condition of more heat removal from one steam generator than from the opposite steam generator. This condition is indicated by a differential pressure between steam generators that is in excess of a pre-selected value.

10.2.2.1 ΔT / ΔT Power Calculations

Since one function of the TMLP trip is to prevent DNB, and DNB varies with power, the TMLP calculation utilizes two power signals. One of the power signals comes from the excore nuclear instrumentation linear power safety channel. The other power signal comes from ΔT power which is calculated by the TMLP calculator. As shown in Figure 10.2-1, each of the four (4) TMLP calculators receive an input from the excore linear power safety channel located in its respective reactor protection system (RPS) channel. The nuclear power input signal is sent to a high select unit (>) that selects the highest of nuclear power or ΔT power.

The ΔT power calculation shown on Figure 10.2-2 uses the following formula:

$$Q = mCp(Th - Tc)$$

The temperatures used in the calculation are average Th and the maximum Tc. The mass flow rate (m) is a constant that is placed into the calculation. The mass flow rate constant is unity for four (4) reactor coolant pump (RCP) operation and less than unity for other pump configurations.

In addition to the ΔT calculation, the calculator also generates terms proportional to the first and second powers of ΔT and to the product of ΔT and Tc. These three (3) terms are used to account for coolant density, specific heat, and flow rate variations with power. To provide an indication during mild transients, such as ramp load changes, a dynamic response term (d/dt) is added to the ΔT.

The output of the ΔT calculation is sent to a high select unit (>), to the LPD calculator, to recorders in the main control room and to the pressure setpoint calculation portion of the TMLP calculator

The high select unit selects the highest of ΔT or excore nuclear power. The selected power is called Q power and is sent to the pressure set point calculator and to the variable overpower trip (VOPT) circuitry. A difference amplifier (Δ) subtracts ΔT power from excore nuclear power and displays the result on a reactor protection system (RPS) meter. If the difference between nuclear power and ΔT power exceeds ± 5%, a control room annunciator will alarm.

When nuclear power is below $10^{-4}\%$ (as sensed by the wide range logarithmic channels) and the zero power mode is selected, the ΔT power input to the high select is defeated. As a result, the high select unit output (Q power) is forced to select the power signal from the excore nuclear instrumentation. The purpose of this interlock is to block the ΔT power calculation when RCS temperatures are below the narrow range values (less than 515°F).

In addition to the input to the high select unit, ΔT power is also supplied to the calculation of LPD. The LPD calculation will also select the highest of ΔT power and excore nuclear power and use the selected signal in the LPD trip set point generation.

ΔT power from the RPS channel A calculation is supplied to two (2) control room recorders. Each of these recorders plots ΔT power (RPS-channel A) and control channel power from one (1) of the two (2) redundant reactor regulating systems (RRS).

As described earlier, the output of the high select unit (Q power) is also supplied to the variable overpower trip. Meters located in the main control room display Q power.

10.2.2.2 Pressure Set point Calculator

The pressure set point calculator (Figure 10.2-3) performs the following functions:

1. Generates a signal (Q_{DNB}) which is a function of core power (Q) modified by penalty factors based on worst case CEA position and calculated ASI. Q_{DNB} is also modified by the input from the FDSS.

2. Generates a variable low pressure trip signal (P_{VAR}) based on inputs from Q_{DNB}, T_{CAL} and the FDSS.

3. Selects the highest of the following:
   - asymmetric steam generator input,
   - the low pressure trip signal (P_{VAR}), or
   - a fixed low pressure trip set point (P_{MIN}),

   and generates the pressure trip signal (P_{TRIP}).

4. Generates a pressure pre-trip ($P_{PRETRIP}$) at 50 psia above the pressure trip signal.

The pressure set point calculator expresses core thermal limits in terms of inlet temperature, axial shape index, core power (multiplied by control element assembly position corrections), and coolant flow. Note that DNB is a function of all of these factors. The combination of these signals generates a three-dimensional power signal. The output of the pressure set point calculator is a conservative pressure limit.

Q_{DNB} is generated as a function of core power (Q), control element assembly (CEA) position and ASI. In the generation of this function, the maximum CEA deviation permitted for continuous operation is assumed. In addition, the required CEA sequencing is also assumed. Finally, the CEAs are assumed to be at the transient insertion limit.

The ASI function is essentially a set of limiting axial power distributions at 100% power as determined from axial shape analysis. The axial shape analysis determines the axial shapes that result in a minimum DNBR (All other DNB factors are held constant). The axial shape analysis includes CEA power dependent insertion limits (PDILs) and an overpower margin. Q_{DNB} is modified by a flow constant, determined by the position of the FDSS.

The second input into the low pressure trip set point calculation is T_{CAL}. Due to temperature differences that can occur in less than full RCS flow conditions, the cold leg RTD may not produce an accurate indication of the hot channel inlet temperature. T_{CAL}, which is a function of ΔT power, compensates the highest Tc for possible temperature differences. In addition, a flow dependent constant determined by the position of the FDSS is applied to the ΔT power input to T_{CAL}.

The final input to the low pressure trip set point calculation is a flow dependent constant determined by the position of the FDSS. Since plant technical specifications prohibit power operation with less than four (4) reactor coolant pumps, most units have modified the flow dependent set point selector to only supply the four (4) pump signal. After all the inputs are combined, a low pressure trip set point (P_{VAR}) is generated.

A plot of P_{VAR} as a function of T_{CAL} is shown in Figure 10.2-4. Once the set point value has been calculated, it is sent to a set point high select unit.

10.2.2.3 Trip Set point Selection

As shown on Figure 10.2-3, the set point high select unit, which provides P_{TRIP} has the following inputs:

1. P_{VAR}.

2. A fixed low pressure set point, P_{MIN}, of 1875 psia and

3. Asymmetric steam generator trip (ASGT) logic circuit.

The fixed set point of 1875 psia ensures that the reactor will be tripped prior to pressure dropping below 1875 psia. In effect, this limits the calculational requirements of the TMLP circuitry by ensuring a reactor shutdown at or below this pressure even though P_{VAR} might calculate a set point below 1875 psia.

The ASGT input (Figure 10.2-5) functions to preclude core radial flux imbalances caused by reduced heat transfer from the RCS to a steam generator whose main steam isolation valve (MSIV) is inadvertently closed. Closing of a MSIV would produce isothermal conditions in one loop. Since less than perfect mixing occurs at the core inlet, one-half of the core would see hot water from the loop associated with the closed MSIV, and the other one-half of the core would see cold water. The negative moderator temperature coefficient may cause unacceptable power peaking in the one-half of the core that is supplied with cold water.

The ASGT calculator receives pressure inputs from each steam generator and calculates a steam generator ΔP. If a ΔP of 135 psid exists, a 2500 psia set point will be sent to the trip set point high select unit in the TMLP pressure setpoint calculator. This set point should be higher than the variable (P_{VAR}) or fixed (P_{MIN}) set points and will be selected by the high select unit. The selection of the 2500 psia set point by two (2) of the four (4) TMLP calculators will result in a reactor trip. ΔPs of less than 135 psid result in a zero input into the trip set point high select unit and have no effect on the TMLP trip calculation.

Regardless of the trip value selected, the output of the high select unit is sent to the TMLP pre-trip and trip circuitry.

10.2.2.4 TMLP Pre-trip Functions

The pre-trip bistable monitors pressurizer pressure and the output of the set point high select unit via a 50 psia bias that is added to the high select unit's output. For example, if the output of the select unit is 2100 psia, the pre-trip bistable would de-energize when actual pressurizer pressure drops to 2150 psia. When the pre-trip bistable de-energizes, a control element withdrawal prohibit (CWP) signal is generated and pre-trip alarms and indication lights are energized. The CWP prevents additional energy from being added to the RCS, and the pre-trip alarms and indication lights alert the plant operators of the possibility of a TMLP trip. Pre-trip functions are disabled in the zero power mode bypass mode of operation. Pre-trip functions are operable above 10^{-4}% power as sensed by the wide range logarithmic power channels.

10.2.2.5 Trip Signal Generation

The output of the set point high select unit is sent to the trip bistable where it is compared with actual pressurizer pressure. If pressurizer pressure equals the set point, a trip signal is generated. Trip functions may be disabled by zero power mode bypass key operation but will be automatically reinstated above 10^{-4}% power as sensed by the wide range logarithmic power channels. The TMLP trip is interlocked when testing the linear power range safety channel. If any power range channel test switch is moved from the operate position, a TMLP trip will be generated in that channel.

10.2.2.6 TMLP Indications

Each TMLP calculator supplies a meter located in the main control room. Each TMLP setpoint meter is next to a pressurizer pressure meter for that particular channel. If both values are equal, a reactor trip signal should be generated.

10.2.3 Local Power Density Trip

The purpose of the LPD trip is to prevent cladding damage caused by high linear heat rates (kW/ft.). High linear heat rates can occur during axial xenon oscillations or improper operation of the CEAs. Linear heat rate is not a readily measurable parameter, but it is calculated in the LPD trip unit using inputs of total power, ASI and the planar radial peaking factor (Fxy).

Power and ASI are direct inputs into the trip calculator, while Fxy is a conservatively fixed input (amplifier gain adjustments) that results from plant safety analysis.

10.2.3.1 LPD Total Power Input

Like the TMLP trip unit, the LPD trip unit (Figure 10.2-6) also uses two power input signals. One based on ΔT power, and the other signal is based on the excore linear power range safety channel. ΔT power is supplied to the LPD trip unit from the TMLP calculation. The linear power range safety channel supplies two inputs to the LPD trip unit. One of the two signals is the average of the upper and lower detector ((L + U)/2) outputs, and the second signal is the difference between the outputs of the lower and upper detectors divided by 2 to normalize the signal to 100% ((L - U)/2). The average of the upper and lower detector signals (total nuclear power) is sent to a high select unit that selects the highest of ΔT power or neutron power. In addition to the input to the high select unit, the average power is sent to a ratio unit for the calculation of ASI. The ratio unit also receives an input from the difference of the lower and upper detectors.

10.2.3.2 Ratio Unit and Shape Annealing

The ratio unit divides the average of the difference in the lower and upper detector outputs ((L - U)/2) by the average of the upper and lower detector outputs ((L + U)/2) to obtain an axial shape index factor called external tilt. This signal is equal to ((L - U)/(L + U)), and is proportional to ASI. Since the upper neutron detector can sense neutrons that originated in the lower half of the core, and the lower detector can sense neutrons that originated in the upper half of the core, a shape annealing correction must be applied to external tilt so that it is truly an ASI signal.

The shape annealing correction factors are derived during testing by comparing incore neutron detector ASI with excore ASI. Various ASIs are generated by inducing axial xenon oscillations. A linear least-squared fit of the data points is performed to yield the shape annealing correction factors. The external tilt is then modified by the shape annealing correction factors to yield internal tilt or ASI.

10.2.3.3 ASI Limit Generation

Nuclear power and ΔT power are supplied to a high select unit where the highest of the two (2) powers is selected for the power signal (Q) in the LPD calculation. Q power is modified by a flow constant determined by the FDSS. The modified Q power signal is supplied to a function generator where it is modified by CEA position. The CEA modification is the same as the modification performed in the TMLP calculator. The modified Q power is sent to the calculation of positive and negative tilt limits.

Positive and negative trip limits, as well as their associated pre-trip limits, are calculated as a function of Q. The tilt limit envelope or tent

(Figure 10.2-7) represents conservative values of ASI and prevents linear heat rate limits from being exceeded. The tilt trip limits and tilt pre-trip limits are supplied to the trip and pre-trip bistables where they are compared with the actual value of internal tilt. As with all RPS trips, if the actual value exceeds the limit, pre-trip and trip signals will be generated.

10.2.3.4 LPD Indications

In addition to the typical pre-trip and trip alarms, the LPD calculation also supplies three (3) main control room meters. One meter displays internal tilt, while the positive and negative trip limits are displayed on the other two meters. If internal tilt is between the limits, LPD trips will not occur.

Q power from each of the four (4) LPD calculations is supplied, via the power ratio calculator, for the generation of pre-power dependent insertion limit (PPDIL) and power dependent insertion limit (PDIL) alarms. The highest of the four (4) Q power signals is selected. An allowable CEA position is calculated that is a function of the highest Q power, and compared to actual CEA position. If the CEAs exceed the allowable CEA position, alarms will be generated to alert the operator. It should be noted that the PPDIL and PDIL limits differ by a constant, and comparisons with both limits are made.

10.2.3.5 LPD/Power Range Interlocks

The LPD trip, like the TMLP trip, is interlocked with the nuclear instrumentation test switches. If any test switch in moved from the operate position, an LPD trip will be generated. Also, the LPD trip is automatically bypassed when nuclear power, as sensed by the linear power range safety channels, is less than or equal to 15%. The bypass is automatically removed when power is increased above 15%.

10.2.4 Summary

The TMLP and LPD trips ensure that DNBR and linear heat rate limits are not exceeded. In addition, the TMLP trip provides protection for asymmetric steam generator conditions. The TMLP trip receives inputs from hot and cold leg temperatures, linear power range safety channels, pressurizer pressure, the flow dependent set point selector, and steam generator pressures. The TMLP trip is bypassed when the zero mode bypass is in effect. The trip is automatically reinstated when power exceeds 10^{-4}%. The LPD trip receives inputs of nuclear power from the linear power range safety channel and ΔT power from the TMLP circuitry. The LPD circuitry provides input to a high select unit that selects the highest of nuclear power or ΔT power. The average power is sent to a ratio unit for the calculation of ASI limits, pretrip values and trip values. The ASI values are displayed in the main control room.

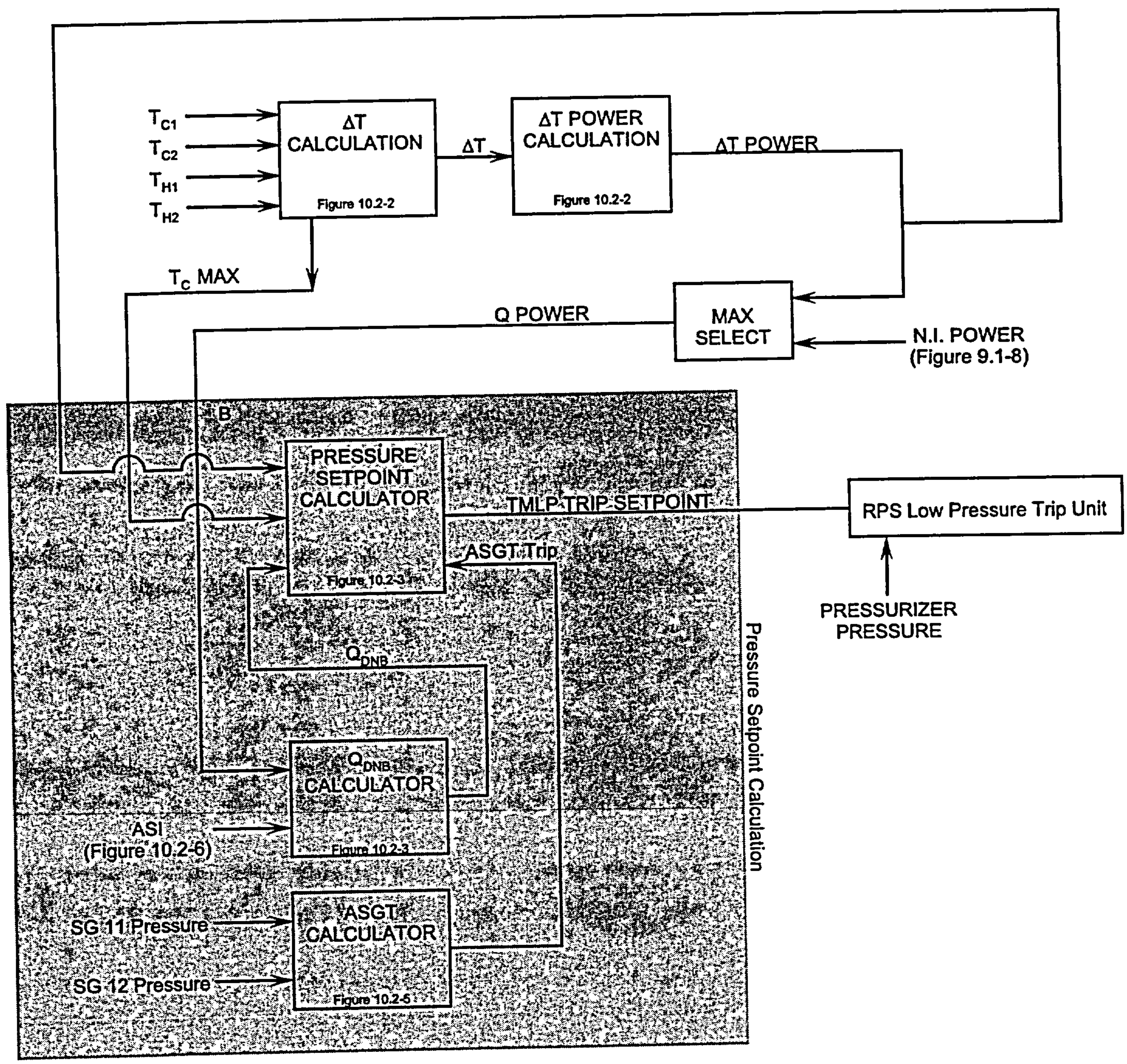


Figure 10.2-1 ΔT/TMLP Calculation Block Diagram

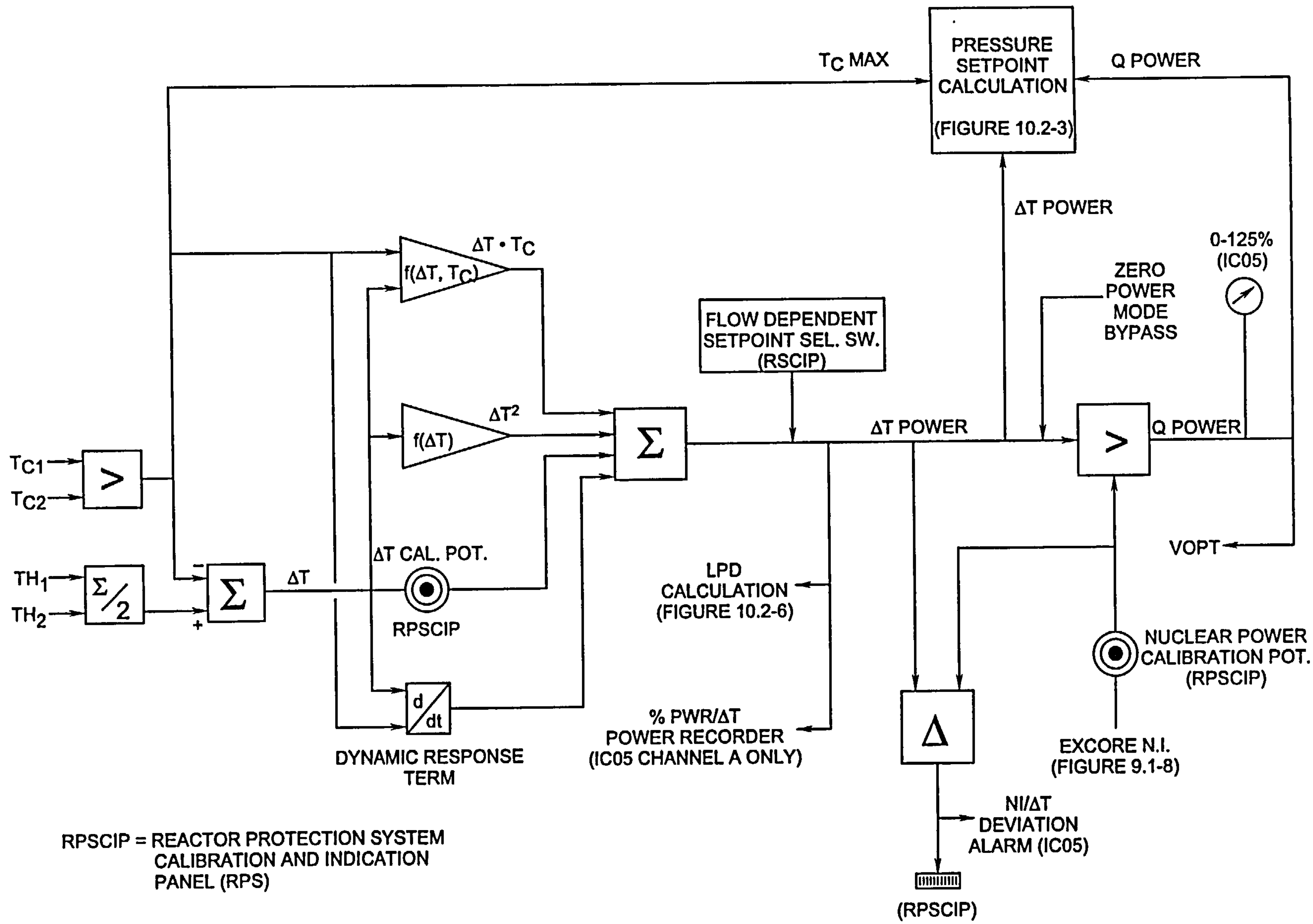
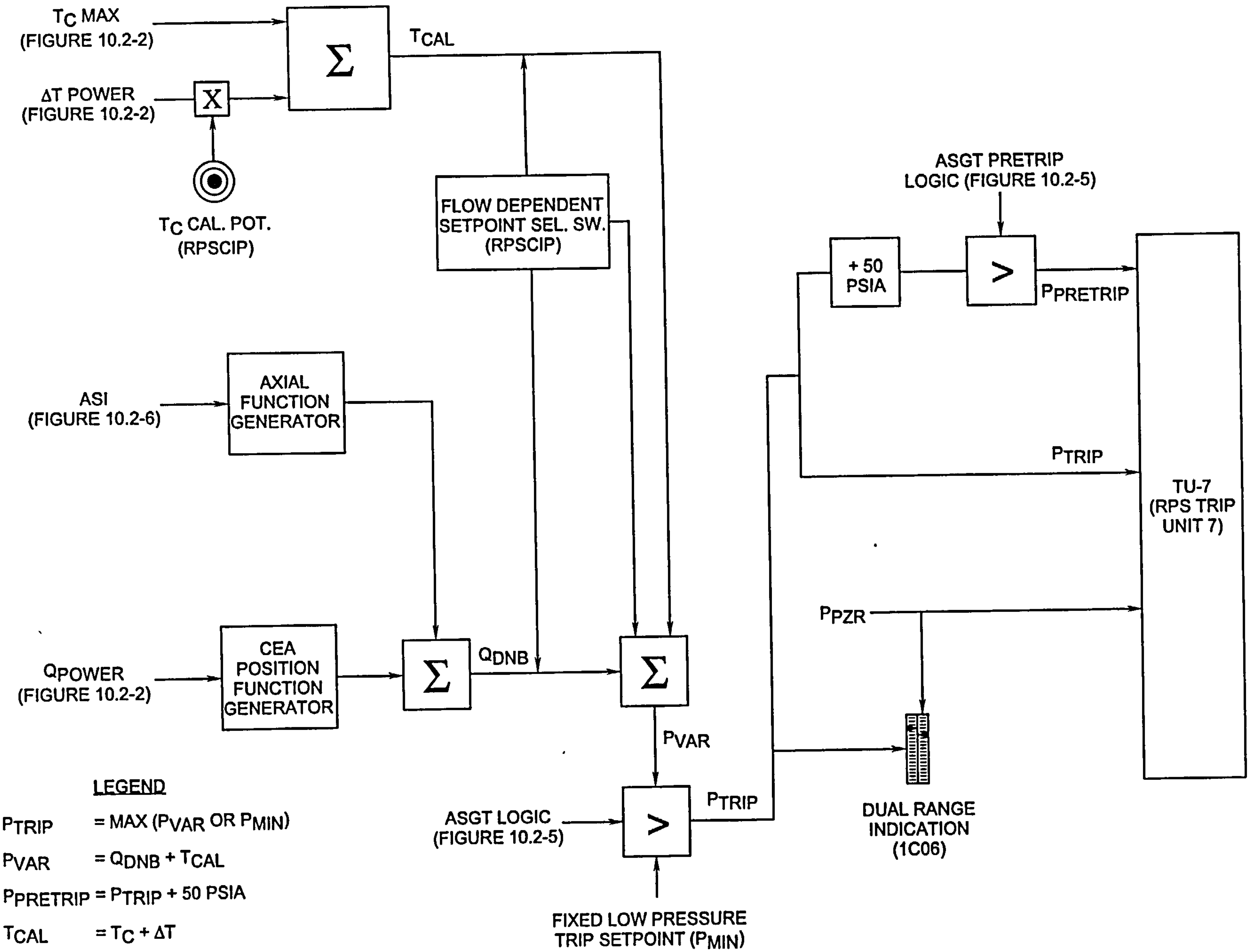


Figure 10.2-2 TMLP ΔT Power Calculation



LEGEND

P_{TRIP} = MAX (P_{VAR} OR P_{MIN})

P_{VAR} = Q_{DNB} + T_{CAL}

$P_{PRETRIP}$ = P_{TRIP} + 50 PSIA

T_{CAL} = T_C + ΔT

Q_{POWER} = MAX (N.I. POWER OR ΔT POWER)

Figure 10.2-3 TMLP Pressure Setpoint Calculation

1000-1C

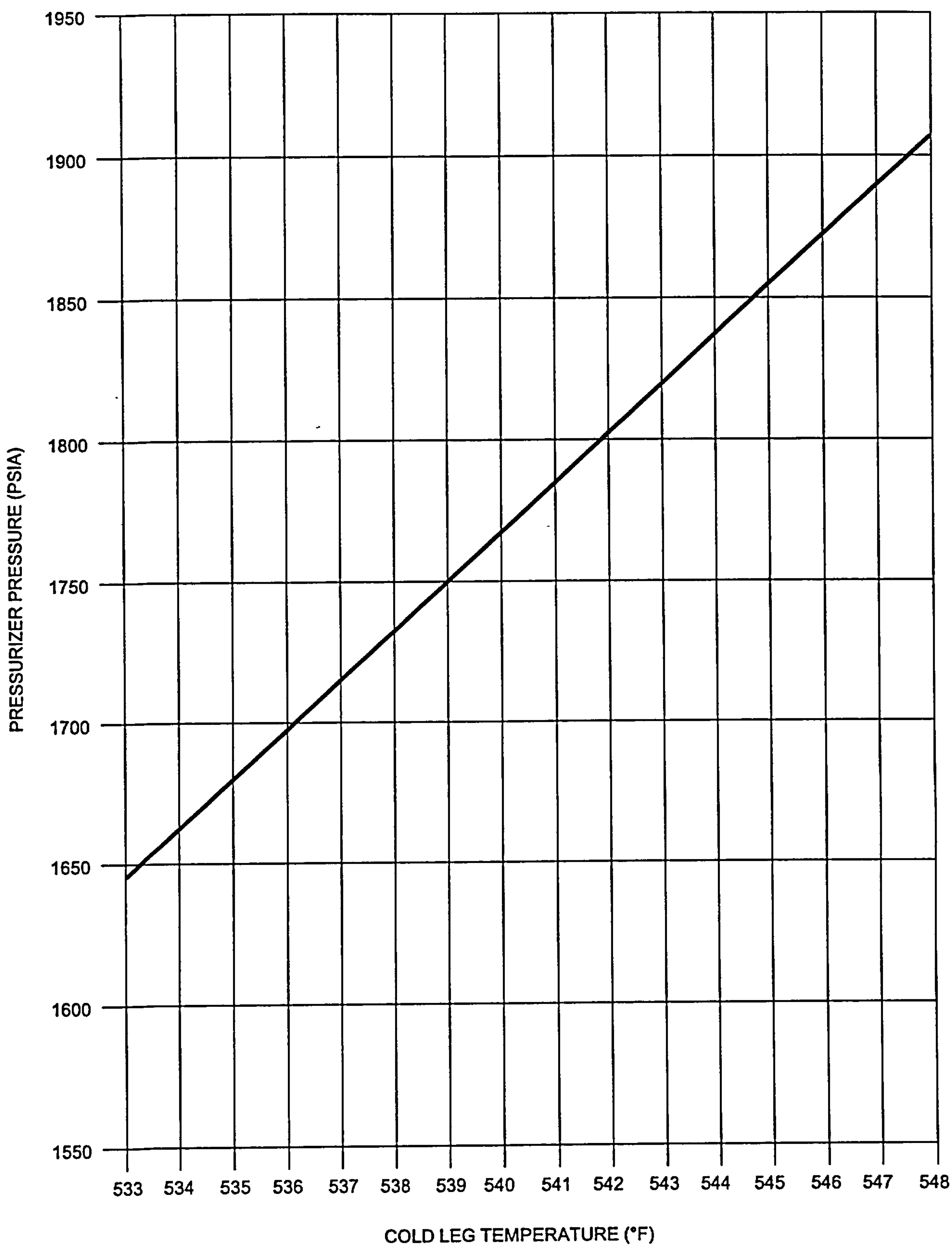


Figure 10.2-4 Pressure Setpoint Versus Temperature

ASGT CALCULATION

If $|\Delta PSG| > ASGT_{Trip}$, Output = 2500 PSI Otherwise Output = 0 PSI

If $|\Delta PSG| > ASGT_{Pretrip}$, Output = 2500 PSI Otherwise Output = 0 PSI

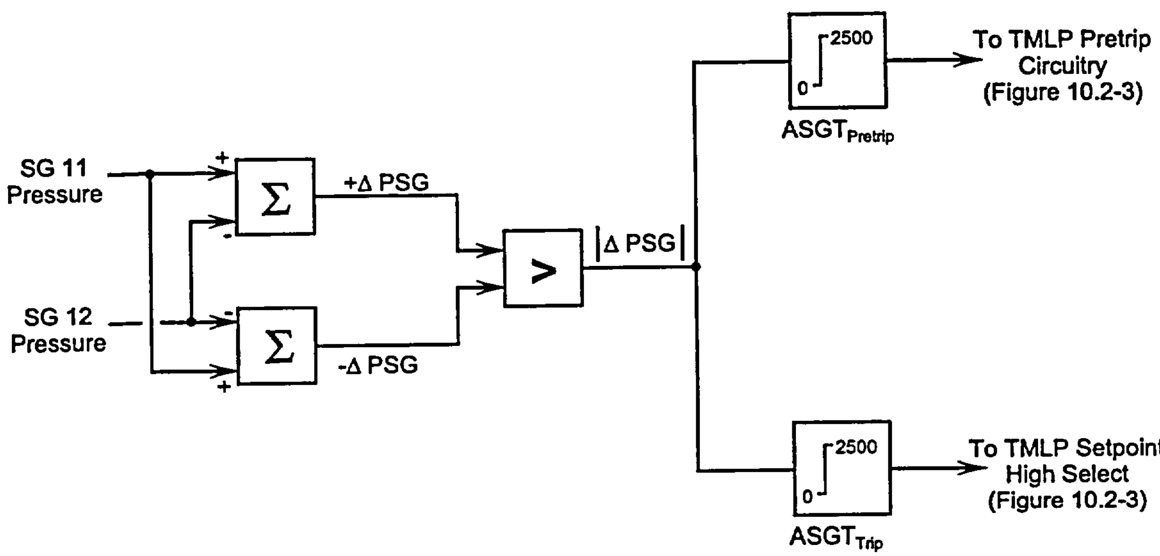


Figure 10.2-5 Asymmetrical Steam Generator Transient Trip Calculator

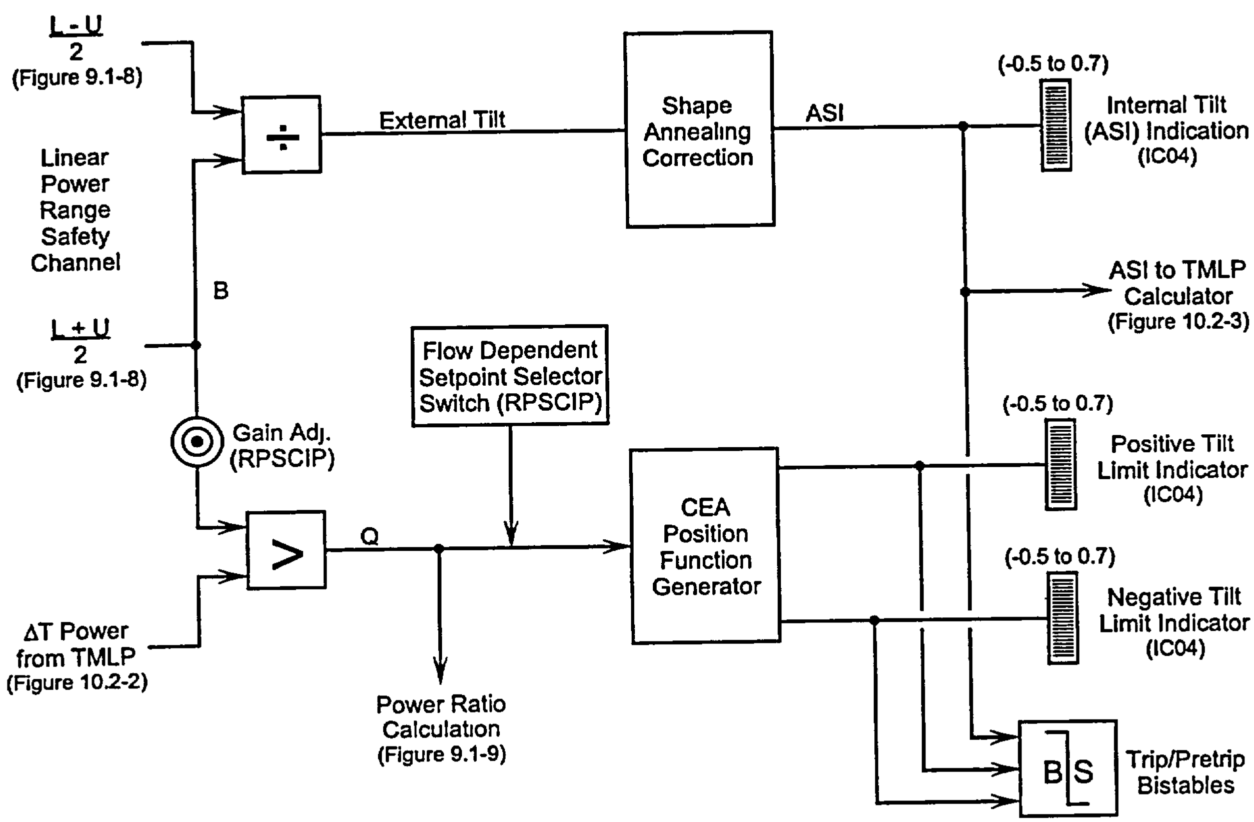


Figure 10.2-6 Local Power Density Trip Block Diagram

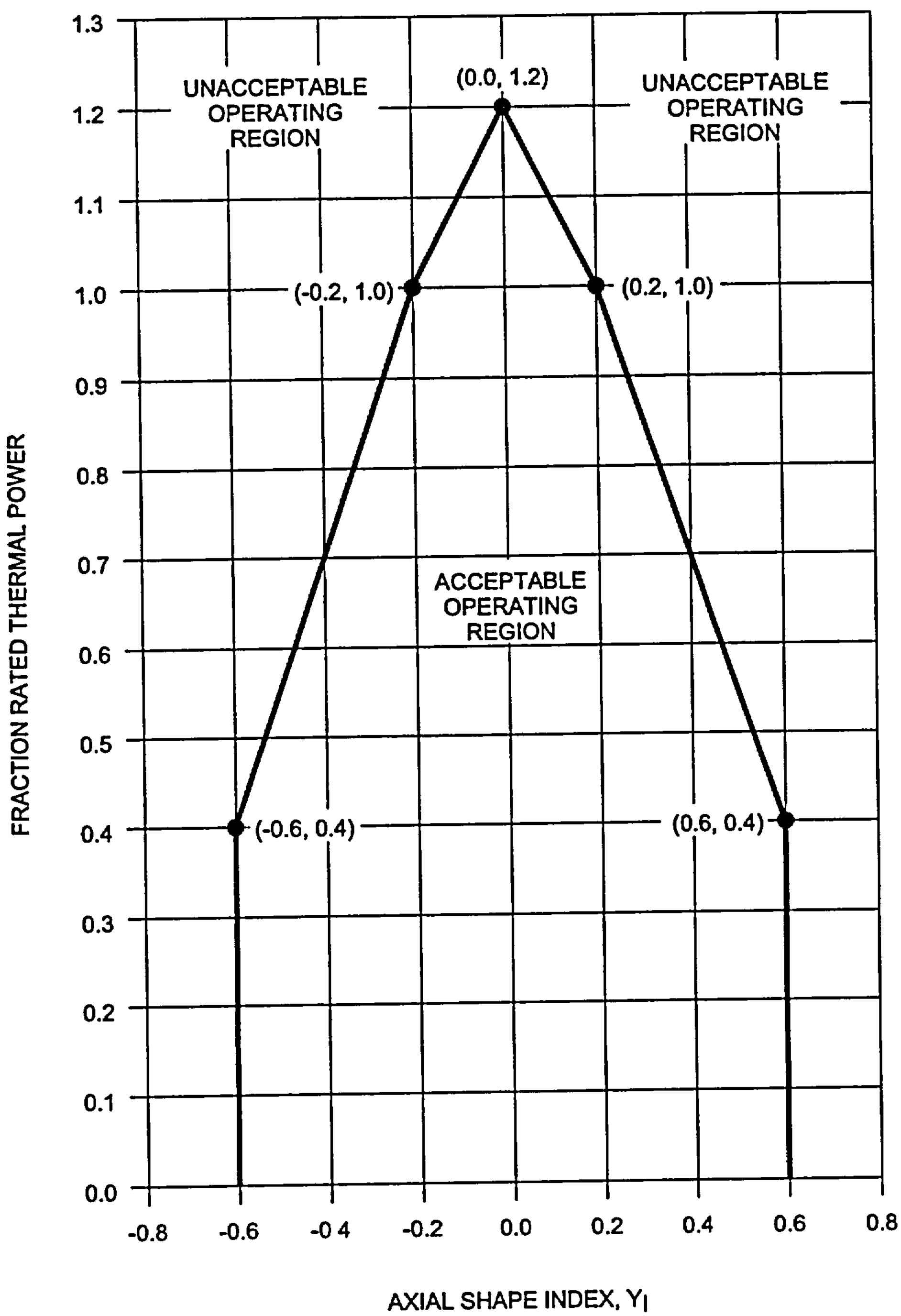


Figure 10.2-7 Axial Shape Index Boundary

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10.3 ENGINEERED SAFETY FEATURES ACTUATION SYSTEM

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10.3 ENGINEERED SAFETY FEATURES ACTUATION SYSTEM

Learning Objectives:

1. State the purposes of the engineered safety features actuation systems (ESFAS).

2. List the inputs, actuation systems, and examples of components that are actuated by the ESFAS.

3. Explain the ESFAS logic.

4. Describe the sequence of events (flow path), beginning at the sensor up to and including the start of an ESF component, that occurs when an accident condition is sensed.

5. Explain how the ESF actuation system(s) is/are designed with redundancy.

6. Explain how ESF systems are bypassed during a normal plant shutdown.

7. Explain how the operator can gain control (override) of an ESF component during an accident.

10.3.1 Introduction

The purposes of the ESFAS is to sense accident related parameters and to actuate equipment that will mitigate the consequences of the accidents. Included in this broad statement is the actuation of equipment that removes core decay heat, provides for long term core cooling, terminates steam line breaks, and protects the containment building fission product barrier.

The ESFAS receives inputs from:

1. Pressurizer pressure,
2. Containment pressure,
3. Containment radiation,
4. Steam generator pressure,
5. Steam generator level,
6. 4160 Vac ESF bus voltage, and
7. Refueling water tank (RWT) level.

The first four (4) input parameters can be used to signal that a loss of coolant accident or steam line break has occurred. The steam generator level input actuates the auxiliary feedwater system (AFW). The 4160 Vac ESF bus voltage input is used to sequence loads onto the diesel generator during accident conditions. Finally, the RWT level input is used to switch the emergency core cooling equipment to the long term core cooling mode of operation.

The input signals are used to actuate eight (8) separate ESF actuation systems as listed below:

1. Safety injection actuation signal (SIAS),
2. Containment spray actuation signal (CSAS),
3. Containment isolation signal (CIS),
4. Recirculation actuation signal (RAS),
5. Containment radiation signal (CRS),
6. Steam generator isolation signal (SGIS),
7. Auxiliary feedwater actuation signal (AFAS), and
8. EDG Sequencing Signal.

10.3.2 System Description

The ESFAS consists of four (4) sensor subsystems that monitor redundant and independent process measurements and generate trip signals when the process variable reaches an unsatisfactory level (set point). Table 10.3-1 lists the setpoints for the various ESFAS parameters. Each subsystem receives one (1) pressurizer pressure input, one (1) containment radiation input, two (2) steam generator pressure inputs (one for each steam generator), two (2) steam generator level inputs (one for each steam generator), one (1) RWT level input, one (1) bus under voltage input, and three (3) containment building pressure inputs.

Each input is monitored by one (1) or, in some cases, two (2) bistables. The bistables provide a trip signal when the input reaches a preset level. When tripped, the bistables provide logic outputs to the actuation subsystems.

The two (2) redundant and independent actuation subsystems monitor the sensor subsystem bistables for trip conditions. If the proper coincidence logic exists, the ESF equipment will be actuated by the actuation subsystems. Figure 10.3-1 shows the general layout of the ESFAS system. As shown in the drawing, the input of the ESF parameter is supplied by a detector to a bistable. The bistable determines if the parameter has exceeded the allowable value and sends an output to the actuation subsystems.

In the actuation subsystem, a determination of proper logic is made. If at least two (2) of the four (4) detectors (as determined by bistable output) have sensed a need for ESF actuation, then each actuation subassembly will actuate ESF equipment. One actuation subassembly activates train "A" equipment, and the other subassembly actuates train "B" equipment.

To illustrate the operation of the sensor and actuation subsystems, assume that the four (4) detectors shown on Figure 10.3-1 are pressurizer pressure detectors. When a loss of coolant accident occurs, pressurizer pressure decreases. When pressure drops to the SIAS set point (1740 psia), the bistables in the sensor subassemblies will sense that an accident is taking place. The bistables will send a signal to the redundant actuation subassemblies. When the actuation subassemblies sense that at least two (2) of the four (4) bistables have actuated, the actuation subassemblies will actuate the ESF equipment. A typical component that is actuated by the SIAS is a high pressure safety injection (HPSI) pump. One of the actuation subsystems will actuate the 11 HPSI pump, and the redundant actuation subsystem will actuate the 12 HPSI pump.

The sensor subsystems bistables turn off (de-energize) when an actuation set point is reached, and the logic sensors in the actuation subsystems turn on (energize) when the proper two (2) out of four (4) logic is sensed. The turn off-turn on characteristic of the bistables affect the operation of the systems when power is lost. If power is lost to a sensor subsystem, all of the bistables in the subsystem will de-energize. This will result in one input to each of the actuation subsystems. Since the subsystems require a two (2) out of four (4) logic, no ESF equipment will actuate. If power is lost to an actuation subsystem, all ESF actuation signals to the equipment in one train would be lost; however, the redundant train equipment would be available for plant protection. In addition, the operator would be able to manually actuate ESF equipment from its normal control station.

10.3.3 Detailed Description

10.3.3.1 Safety Injection Actuation Signal (SIAS)

The SIAS initiates operation of equipment that is necessary for core cooling and to ensure adequate shutdown of the reactor in the event of a LOCA, a main steam line break, or a main feedwater line break inside of the containment. In order to provide protection for these accidents, the SIAS monitors pressurizer and containment building pressures.

Each of the four (4) pressurizer pressure transmitter inputs (Figure 10.3-2) provides a signal to the reactor protection system (RPS) and the ESF actuation logic. In the ESF actuation logic, the pressurizer pressure signal is routed to two (2) bistables. The first of these bistables compares the detector's signal with a set point of 1740 psia and is used to initiate the SIAS. The second bistable compares the detector's output with a set point of 1785 psia. The actuation signal flow path will be described first.

From the 1740 psia bistable, the signals are sent to the redundant actuation subsystems where the two (2) out of four (4) logic is sensed. The output of the two (2) out of four (4) logic circuits is routed to the SIAS initiation AND gate where it is combined with the pressurizer pressure block logic. The pressurizer pressure block must not be initiated for the signal to pass through the SIAS initiation AND gate. From the output of the SIAS initiation AND gate, the low pressurizer pressure signal is sent to the SIAS initiation OR gate where it is combined with the high containment building pressure signal. If either two (2) out of four (4) low pressurizer pressure signals or two (2) out of four (4) high containment building pressure signals are sensed, a SIAS signal will be generated. Once a SIAS signal is generated, it is sealed in by a loop from the output of the SIAS OR gate to its input via the SIAS reset circuitry.

The containment building pressure SIAS input is relatively simple in comparison to the pressurizer pressure input signal. Each of the four (4) containment building pressure transmitters supply a signal to the RPS and the ESF actuation logic. In the ESF logic, the signal is routed to a bistable where it is compared to a two and eight-tenths (2.8) psig set point. From that bistable, the signal is sent to the redundant actuation subsystems where the two (2) out of four (4) logic is sensed. The output of the two (2) out of four (4) logic circuit is transmitted to the SIAS initiation OR gate. Again, if either two (2) out of four (4) low pressurizer pressure signals or two (2) out of four (4) high containment building pressure signals are sensed, an SIAS signal will be generated.

In addition to the pressurizer pressure and the containment building pressure inputs into the SIAS initiation OR gate, the OR gate also receives an input from a manual push-button. The manual push-button is installed to allow the operator to manually initiate SIAS if plant conditions warrant (pressurizer level is decreasing with all three charging pumps running, which is indicative of a LOCA and the operator needs to add inventory to the RCS) or if a failure of the automatic initiation circuitry occurs.

As previously discussed, once an SIAS signal is generated, it is sealed in. If the parameter(s) that caused the generation of the signal return to an untripped value (pressurizer pressure > 1740 psia or containment building pressure < 2.8 psig), the SIAS signal can be reset by depressing the SIAS reset push-button. When this push-button is actuated, the last of the remaining inputs to the SIAS initiation OR gate is removed. The equipment that received the SIAS signal can now be controlled normally.

The SIAS signal operates equipment to provide emergency core cooling, adds boric acid to the RCS, isolates RCS and containment penetrations, realigns cooling water systems, places the emergency diesels in a standby condition, and opens the containment spray header isolation valves.

The following is a list of SIAS actuated components:

1. Emergency Core Cooling Systems

   a. Starts two (2) HPSI pumps,
   b. Opens eight (8) HPSI injection valves,
   c. Opens the HPSI auxiliary header isolation valve (if closed),
   d. Opens HPSI recirculation valves (if closed),
   e. Starts two (2) LPSI pumps,
   f. Opens four (4) LPSI injection valves, and
   g. Opens four SIT outlet isolation valves (if closed).

2. Boric Acid Addition
   a. Starts two (2) boric acid pumps,
   b. Starts three (3) charging pumps,
   c. Opens the gravity feed valves,
   d. Opens the boric acid addition motor-operated valve,
   e. Boric acid pump recirculation valves close and
   f. VCT outlet valves close.

3. RCS and containment penetrations

   a. Closes the letdown loop isolation valves,
   b. Closes the RCP controlled bleed off valves,
   c. Closes the RCDT containment isolation valve, and
   d. Closes the RCS sample valves.

4. Cooling water system realignments

   a. Starts two (2) service water pumps,
   b. Isolates service water to the turbine building,
   c. Starts two (2) component cooling water pumps,
   d. Opens the CCW supply to the shutdown cooling heat exchangers, and
   e. Starts two (2) salt water pumps.

5. Emergency diesel generators are started.

6. Opens both spray header isolation valves.

When the plant is being cooled down, pressurizer pressure is decreased. To prevent unnecessary actuation of SIAS during a plant cool down, a method of bypassing the low pressurizer pressure condition is incorporated in the design of the ESF. As shown in Figure 10.3-2, the pressurizer pressure transmitter supplies an input to a bistable with a set point of 1785 psia. From the bistable, the signal is routed to a three (3) out of four (4) logic circuit. The output of the three (3) out of four (4) logic circuit is supplied to the pressurizer pressure block AND gate, where it is combined with a key operated block switch. As the plant is intentionally depressurized, the operator receives an alarm when at least three (3) out of the four (4) pressurizer pressure transmitters sense a pressure of less than 1785 psia. The operator places the key operated block switch in the bypass position, satisfying both input conditions to the pressurizer pressure block AND gate. The output of pressurizer pressure block AND gate is sealed in, and the operator may remove the key from the block switch if desired. It should be noted that when pressurizer pressure exceeds 1785 psia, the three (3) out of four (4) input to the pressurizer pressure block AND gate will be lost, and the pressurizer pressure block will automatically be removed.

10.3.3.2 Containment Isolation Signal (CIS)

The isolation of containment during a loss of coolant accident minimizes the leakage paths for fission products through non-safety related penetrations. The containment isolation signal (CIS) is generated by high containment building pressure.

As shown in Figure 10.3-3, four (4) independent containment building pressure transmitters supply the CIS with inputs. Each transmitter supplies an input to a bistable in the sensor subsystem. If pressure equals or exceeds two and eight-tenths (2.8) psig, the bistable de-energizes and sends a signal to the two (2) out of four (4) logic circuits in the actuation subassemblies. If at least two (2) bistables de-energize, a CIS signal is generated. Once initiated, the CIS signal seals in via the CIS reset circuitry. CIS can also be manually initiated by the operator.

The CIS signal actuates the following equipment:

1. CCW is isolated to the RCPs,
2. Containment penetration room ventilation units start,
3. Containment iodine removal system is placed in service, and
4. Containment instrument air supply is isolated.

As previously discussed, once a CIS signal is generated, it is sealed in. If the parameter(s) that caused the generation of the signal return to an untripped value (containment building pressure < 2.8 psig), the CIS signal can be reset by depressing the CIS reset push-button. When this push-button is actuated, the last of the remaining inputs to the CIS initiation OR gate is removed. The equipment that received the CIS signal can now be controlled normally.

10.3.3.3 Containment Spray Actuation Signal (CSAS)

Four (4) independent containment building pressure transmitters (Figure 10.3-4) provide signal inputs to the CSAS. These pressure transmitters are separate from those used for SIAS and CIS. The actuation circuitry for CSAS is identical, with the exception of a four and one-quarter (4.25) psig set point, to the circuitry for the CIS.

The CSAS automatically initiates operation of the equipment required to provide adequate containment cooling. Containment cooling reduces the pressure inside of the containment following an accident which minimizes the driving force for the leakage of fission products and reduces containment building stresses.

The CSAS signal actuates the following equipment:

1. Starts two (2) containment spray pumps,
2. Starts the containment cooling fans,
3. Opens the service water outlets from the containment building cooling fans,
4. Closes the main steam isolation valves (MSIVs), main feedwater isolation valves (MFIVs), and
5. Trips the main feedwater pumps, the condensate booster pumps, and the heater drain pumps.

To prevent an inadvertent CSAS actuation in the event of an undesired trip of the CSAS equipment, the containment spray header isolation valves are opened by the SIAS.

10.3.3.4 Recirculation Actuation Signal (RAS)

Four (4) independent refueling water tank (RWT) level switches provide inputs to the RAS (Figure 10.3-5). Actuation of the RAS occurs automatically as a result of either two (2) out of four (4) low RWT water level trip signals or from manual initiation. The operation of the circuitry is identical to the CIS circuitry.

The RAS initiates operation of the equipment necessary to provide a continuous source of water for decay heat removal and containment spray. The following list summarizes the actions that occur when a RAS is generated:

1. The containment sump suctions open,
2. The LPSI pumps are stopped,
3. The LPSI, HPSI, and containment spray pump minimum recirculation valves close, and
4. The CCW heat exchanger salt water valves open.

10.3.3.5 Containment Radiation Signal (CRS)

Four (4) independent radiation detectors located within the containment building provide signal inputs to the CRS actuation circuitry. Actuation of CRS occurs automatically as a result of either two (2) out of four (4) high radiation detector channel trip signals or from manual initiation.

A CRS automatically operates the equipment necessary to limit the release of fission products during refueling and maintenance periods when containment integrity is breached. The CRS isolates the containment purge system by stopping the purge supply and exhaust fans and closing the containment purge valves.

10.3.3.6 Steam Generator Isolation Signal (SGIS)

Four (4) independent steam generator pressure transmitters for each steam generator (Figure 10.3-6) provide inputs to the SGIS. Since the inputs for each steam generator are identical, only one of the steam generator inputs will be discussed. The steam generator pressure transmitter supplies an input to two (2) bistables; a SGIS actuation bistable with a set point of 703 psia, and a SGIS block bistable with a set point of 767 psia.

From the 703 psia bistable, the signals are sent to the redundant actuation subsystems where the two (2) out of four (4) logic is sensed. The output of the two (2) out of four (4) logic circuits is routed to the SGIS initiation AND gate where it is combined with the steam generator pressure block logic. The steam generator pressure block must not initiated for the signal to pass through the SGIS initiation AND gate. From the output of the SGIS initiation AND gate, the low steam generator pressure signal is sent to the SGIS initiation OR gate where it is combined with the manual push-button signal. If either two (2) out of four (4) low steam generator pressure signals are sensed or the manual push-button is depressed, an SGIS signal will be generated. Once a SGIS signal is generated, it is sealed in by a loop from the output of the SGIS initiation OR gate to its input via the SGIS reset circuitry. The equipment that is operated by the SGIS and its interface with the CSAS is shown in Figure 10.3-7.

When the plant is being intentionally cooled down, steam generator pressure will decrease as RCS temperature is decreased. To prevent unnecessary actuation of SGIS during a plant cool down, a method of bypassing the low steam generator pressure condition is incorporated in the design of the ESFAS. As shown in Figure 10.3-6, the steam generator pressure transmitter supplies an input to a bistable with a set point of 767 psia. From the bistable, the signal is routed to a three (3) out of four (4) logic circuit. The output of the three (3) out of four (4) logic circuit is supplied to the steam generator pressure block AND gate where it is combined with a key operated block switch. As the plant is intentionally cooled down, the operator receives an alarm when at least three (3) out of the four (4) steam generator pressure transmitters sense a pressure of less than 767 psia. The operator places the key operated block switch in the bypass position, and both input conditions to the steam generator pressure block AND gate are satisfied. The output of the steam generator pressure block AND gate is sealed in, and the operator may remove the key from the block switch if desired. It should be noted that when steam generator pressure exceeds 767 psia, the three (3) out of four (4) input to the steam generator pressure block AND gate will be lost, and the steam generator pressure block will automatically be removed.

10.3.3.7 Diesel Generator Sequencing Signal

The diesel generator sequencing signal functions to provide an emergency source of power for the operation of the 4160 Vac distribution system through the application of load shedding and sequential reloading. The sequencing circuitry also prevents overloading of the diesel generators by the sequencing of heavy electrical loads.

The sequencing circuit is supplied with inputs that sense under voltage (UV) conditions on the 4160 Vac ESF busses. As in all ESF systems, the circuitry uses a two (2) out of four (4) coincidence logic; however, the output of this ESF circuitry is dependent upon plant conditions.

If a loss of power occurs without a coincident SIAS signal, the sequencer automatically energizes selected essential loads at five (5) second intervals. The selected loads include the service water pumps, the salt water pumps, and the instrument air compressors. If a loss of power and a SIAS is sensed at the same time, the load sequencing of the diesel generators will include safety related pumps such as the HPSI and LPSI pumps.

10.3.3.8 Auxiliary Feedwater Actuation System (AFAS)

The actuation of auxiliary feedwater (AFW) by the AFAS ensures that the steam generators will be available as a RCS heat sink. The ability to transfer decay heat to the steam generators is important for anticipated operational occurrences such as a loss of main feed and for small break loss of coolant accidents.

The AFAS receives inputs from four (4) channels of level indication from each steam generator (Figure 10.3-8). Each transmitter signal feeds a low level bistable where it is compared with a fixed set point of 40% wide range. If actual steam generator level drops to the setpoint, the bistable will trip. The output of the bistable is supplied to two (2) two (2) out of four (4) logics.

There are two (2) two (2) out of four (4) logics associated with each steam generator. Each of the logics receives four (4) low level inputs from its associated steam generator. If at least two (2) level transmitters sense that the steam generator level has dropped to the actuation set point, the two (2) out of four (4) logic will have an output. The output signal from the four (4) two (2) out of four (4) logics enter two (2) AFW start OR gates. The OR gates provide redundant actuation signals to start the AFW system. Each AFW start logic may be manually initiated and manually reset when level returns to set point. Figure 10.3-8 omits these features for simplicity.

10.3.3.9 Diverse Scram System (DSS)

Over the years, new safety issues have surfaced and these issues have required ESF system modifications. One such issue is the anticipated transient without a scram (ATWS). Combustion Engineering designed plants were required to backfit a DSS to provide protection for the ATWS. Calvert Cliffs utilized the ESF narrow range pressurizer pressure input to actuate the DSS on high RCS pressure.

10.3.4 Engineered Safety Features Actuation System Design Basis

The ESFAS conforms to the provisions of the Institute of Electrical & Electronic Engineers (IEEE) 279 "Criteria for the Protection for Nuclear Power Generating Stations". Consideration was given to the following criteria:

Single Failure - No single fault in the components, modules, channels, or sensors of the ESFAS prevents engineered safety features operation. The wiring is installed so that no single fault or failure, including either an open or shorted circuit, negates minimum engineered safety features operations. Wiring for redundant circuits is protected and routed so that damage to any one path does not prevent minimum engineered safety features action. The sensors are piped so that blockage or failure of any one connection does not prevent engineered safety features operation.

Quality of components and modules - Components and modules must exhibit a quality consistent with the nuclear power plant 40 year design life objective, with minimum maintenance requirements and low failure rates.

Channel independence - Independence is provided between redundant subsystems (sensor and actuation) or channels to accomplish separation of the effect of unsafe environmental factors, reduce the likelihood of interactions between channels during maintenance operations or in the event of channel malfunction. Independence is obtained by electrical isolation, physical separation, and system repair.

Electrical isolation is provided between redundant channels, between sensor and actuation subsystems, and between the ESFAS and auxiliary equipment. Electrical isolation ensures that an electrical fault does not inhibit a protective action as a result of a redundant system.

Physical separation is maintained between redundant sensor subsystems, between sensor and actuation subsystems, and between redundant subsystems. This is accomplished by the use of separate and isolated cabinets for each of the four sensor subsystems and each of the two actuation subsystems.

With regard to system repair, the ESFAS is designed such that routine servicing and maintenance is performed without interfering with plant operation and without loss of the ESFAS function. Performance of maintenance and testing will not result in simultaneous availability of both actuation subsystems.

For further protection and reliability, the ESFAS modules are standardized and interchangeable, and have a minimum number of interconnections and interwiring. Withdrawal of or loss of power to a sensor module results in a trip signal to its associated two (2) out of four (4) logic. Withdrawal of two (2) sensor modules of a common actuation signal results in a trip of the associated actuation channel. Withdrawal of an actuation logic module does not result in a trip of that channel.

The ESFAS has also been designed to satisfy seismic and environmental requirements. The system is seismic Class I and is designed to withstand all simultaneous horizontal and vertical accelerations resulting from the design basis earthquake without loss of functions. All components required to operate in a loss of coolant accident environment are tested at the expected temperature, pressure, and humidity conditions.

10.3.5 Summary

The engineered safety features actuation system is designed to monitor plant parameters and conditions, and to effect and maintain reliable and rapid safety equipment operation if any one or combination of conditions deviates from a preselected setpoint. Proper operation of the ESFAS protects the public from the accidental release of radioactive fission products in the event of a loss of coolant accident, steam line break, or feedwater line break.

TABLE 10.3-1

ESF SETPOINT SUMMARY

System	Setpoint	Bypass Setpoint
Safety Injection Actuation Signal		
Pressurizer Pressure	1740 psia	1785 psia
Containment Pressure	2.8 psig	None
Containment Isolation Signal		
Containment Pressure	2.8 psig	None
Containment Spray Actuation Signal		
Containment Pressure[1]	4.25 psig	None
Recirculation Actuation Signal		
RWT Level	30 inches	None
Steam Generator Isolation Signal		
Steam Generator Pressure[1]	703 psia	767 psia
Auxiliary Feedwater Actuation Signal		
Wide Range Steam Generator Level	40%	None

Notes:

[1]Will also close the MSIVs and MFIVs. In addition, the MFPs, heater drain pumps, and the condensate booster pumps are tripped.

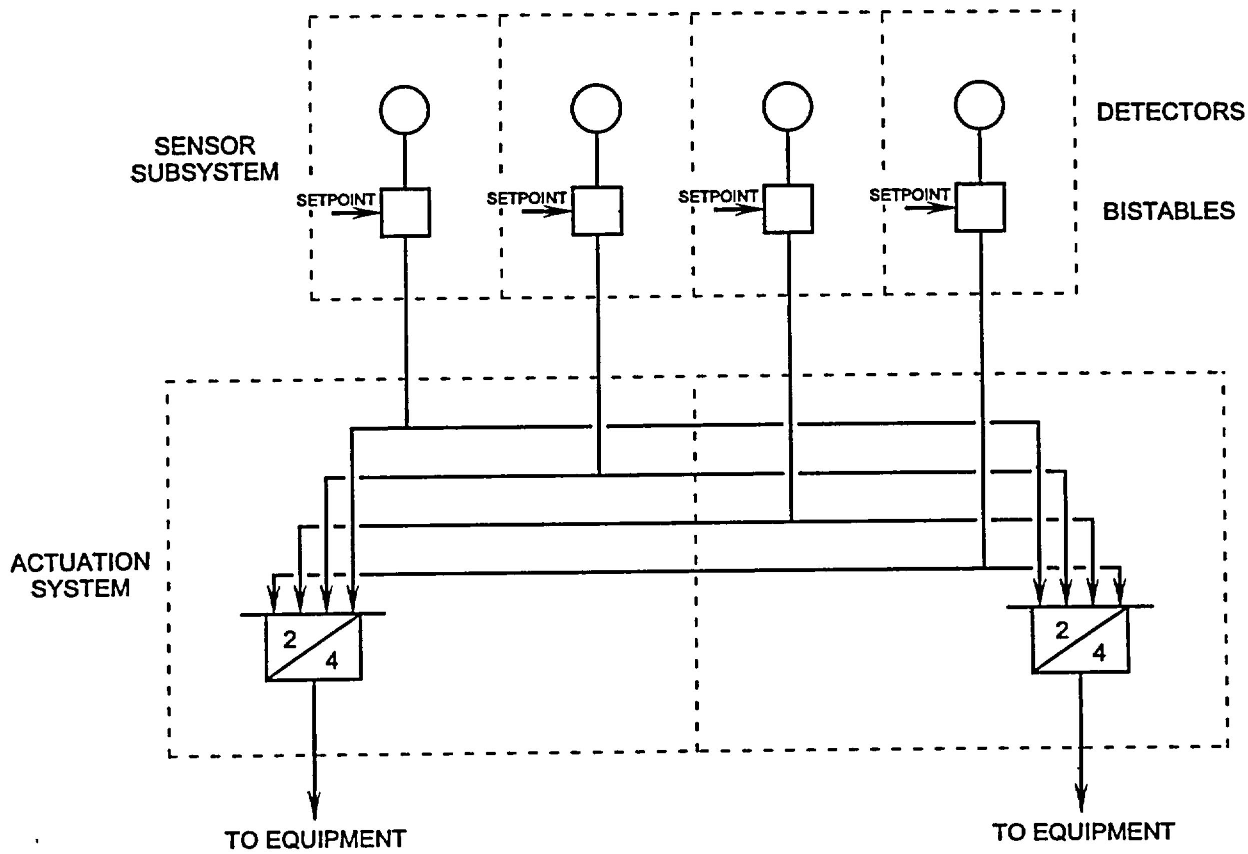
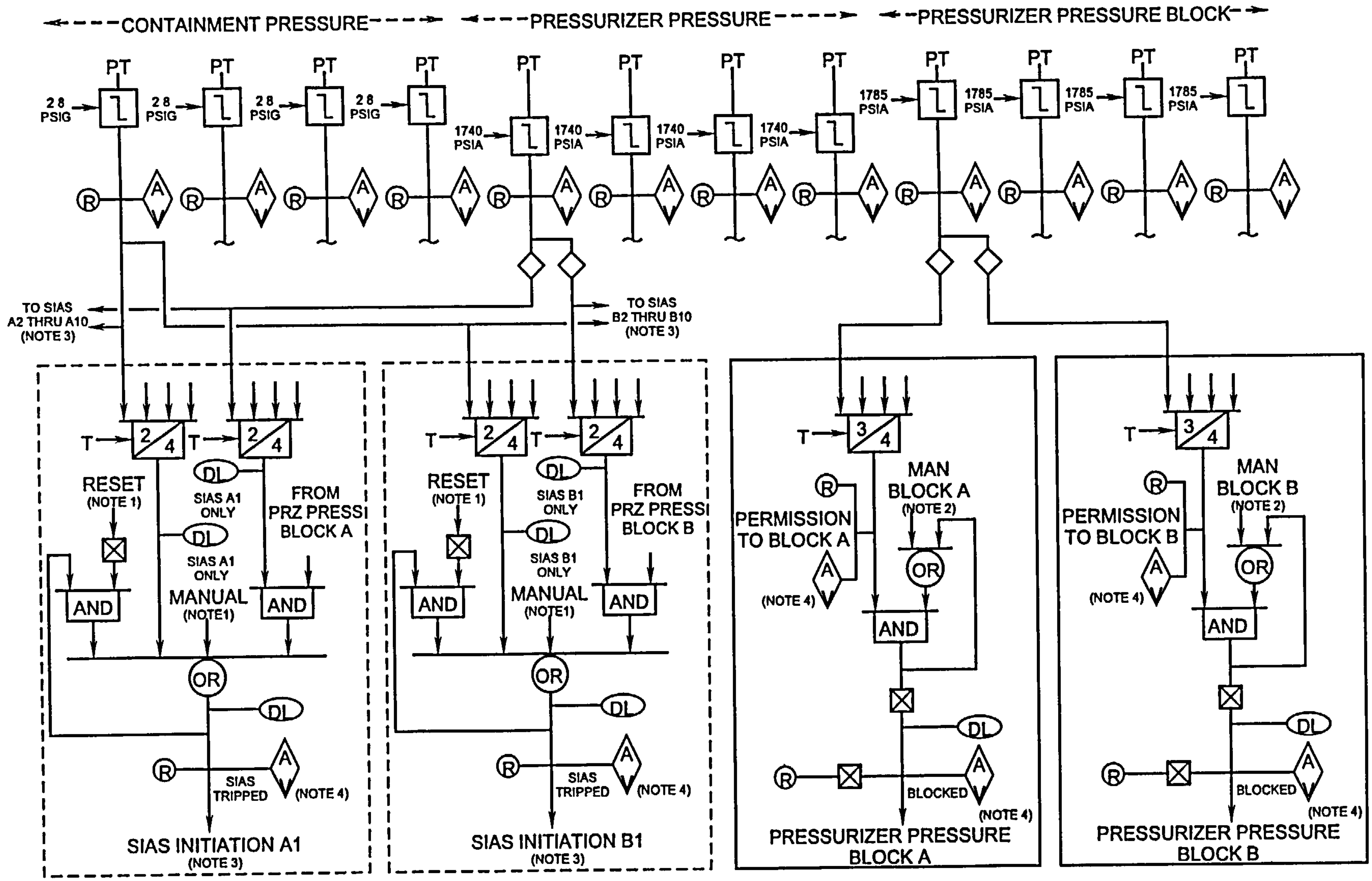


Figure 10.3-1 ESF Organization



T TEST

PT PRESSURE TRANSMITTER

R LOCAL RED INDICATING ALARM LIGHT

DL OUTPUT TO PLANT COMPUTER

A REMOTE AUDIBLE VISUAL ALARM

◇ ISOLATION

NOTE 1 THIS SIGNAL IS INITIATED BY A REMOTE PUSHBUTTON (ONE PER CHANNEL) ON CONTROL ROOM PANEL 1C10 AND BY LOCAL PUSHBUTTONS (ONE PER CHANNEL) ON THE ASSOCIATED LOGIC ACTUATION CABINET.

NOTE 2 THIS SIGNAL IS INITIATED BY A REMOTE KEYSWITCH (ONE PER CHANNEL) ON CONTROL ROOM PANEL 1C10.

NOTE 3 THIS SIGNAL IS ALSO INITIATED BY LOCAL PUSHBUTTONS (ONE PER CHANNEL) ON THE ASSOCIATED LOGIC ACTUATION CABINET.

NOTE 4 ALL REMOTE ALARMS ARE LOCATED ON CONTROL ROOM PANEL 1C08

Figure 10.3-2 Safety Injection Actuation Signal Logic

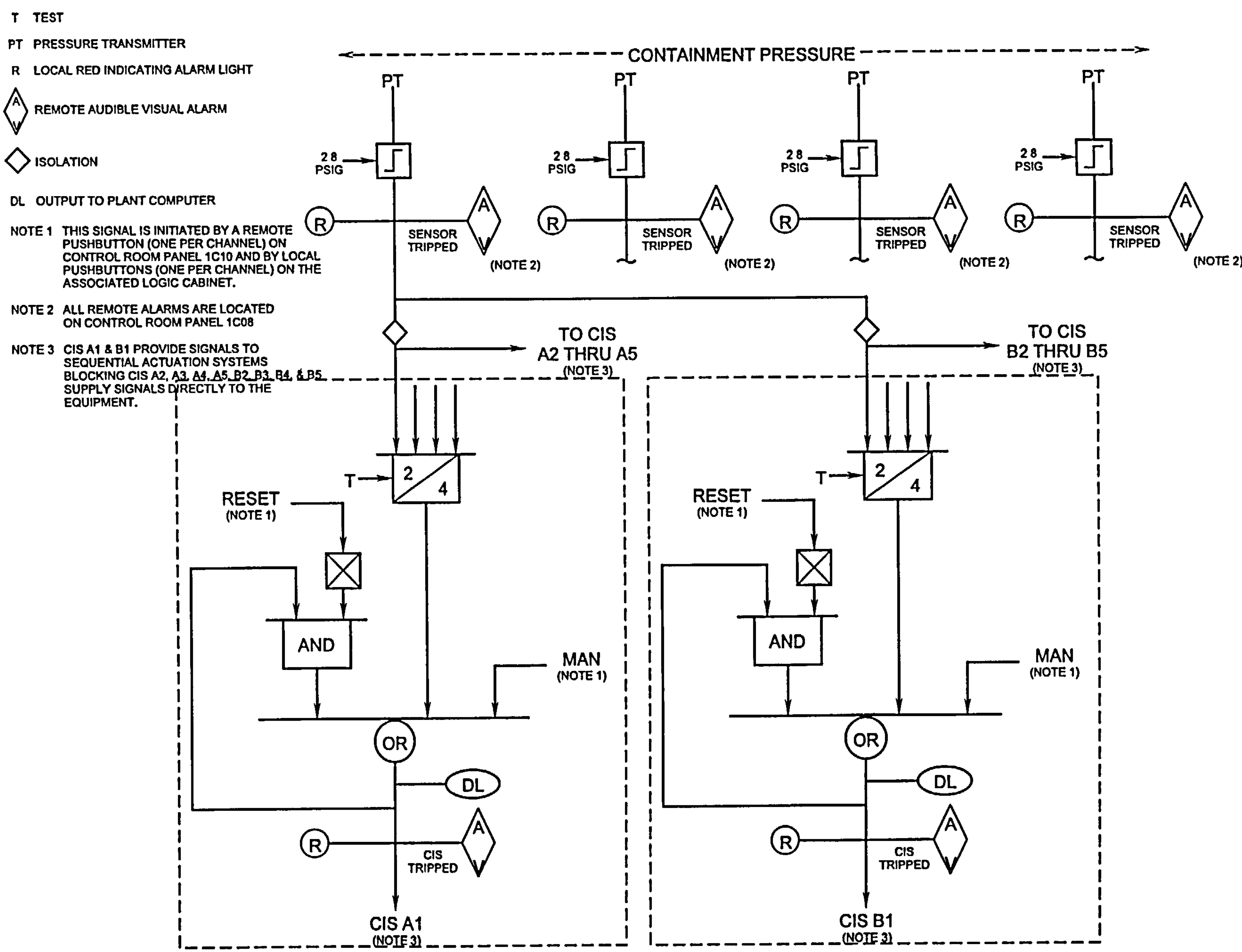


Figure 10.3-3 Containment Isolation Actuation Signal Logic

1000-1

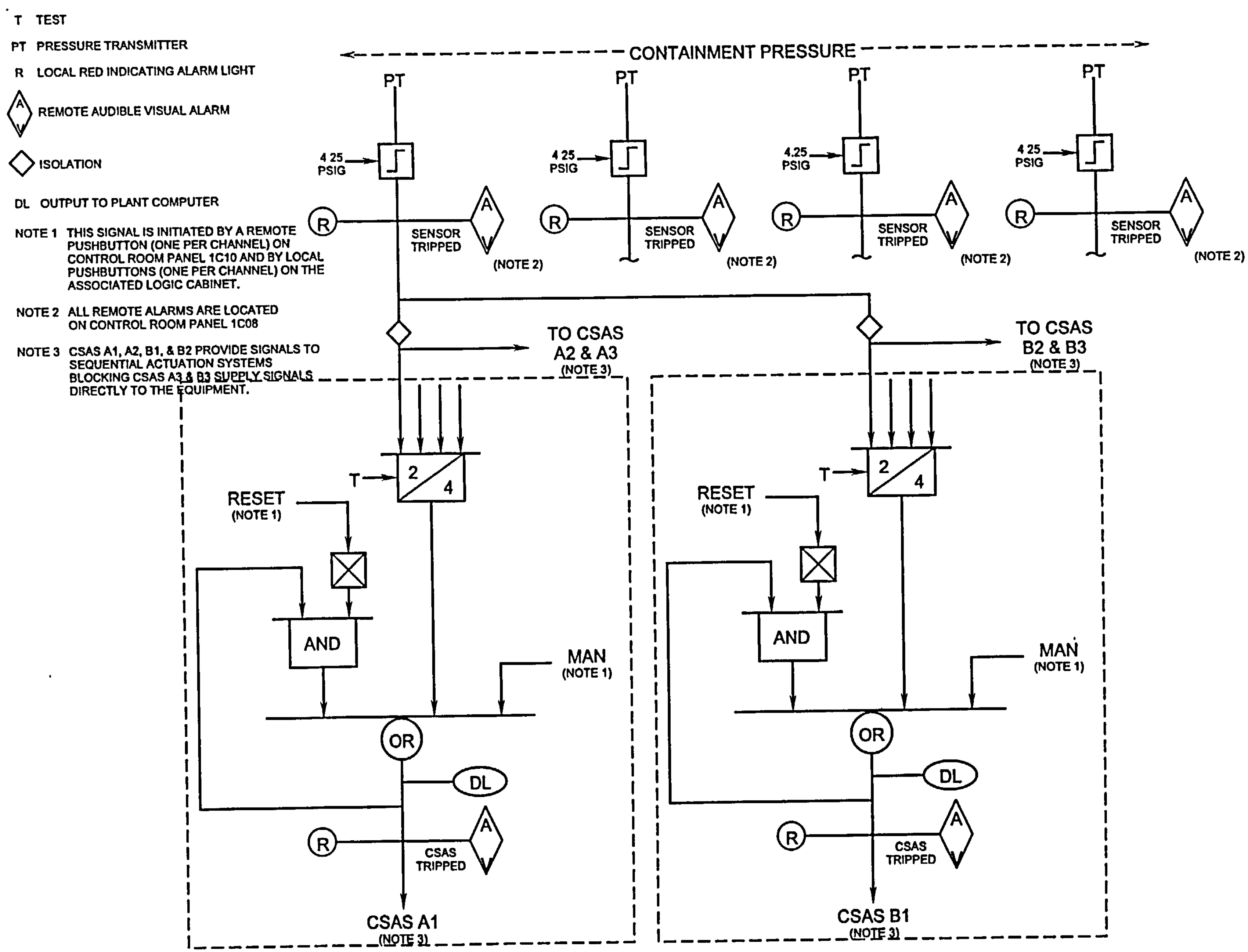


Figure 10.3-4 Containment Spray Actuation Signal Logic

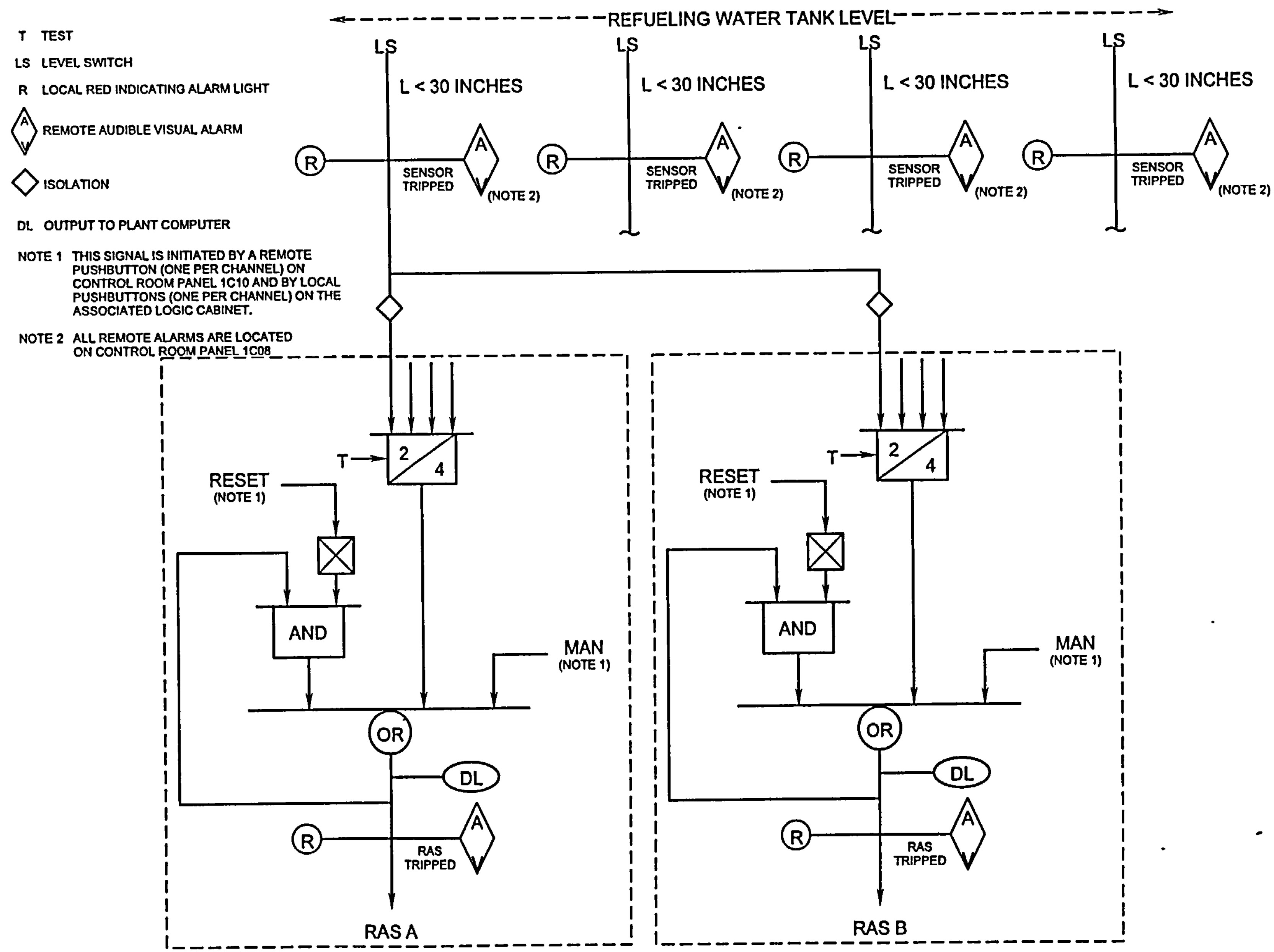
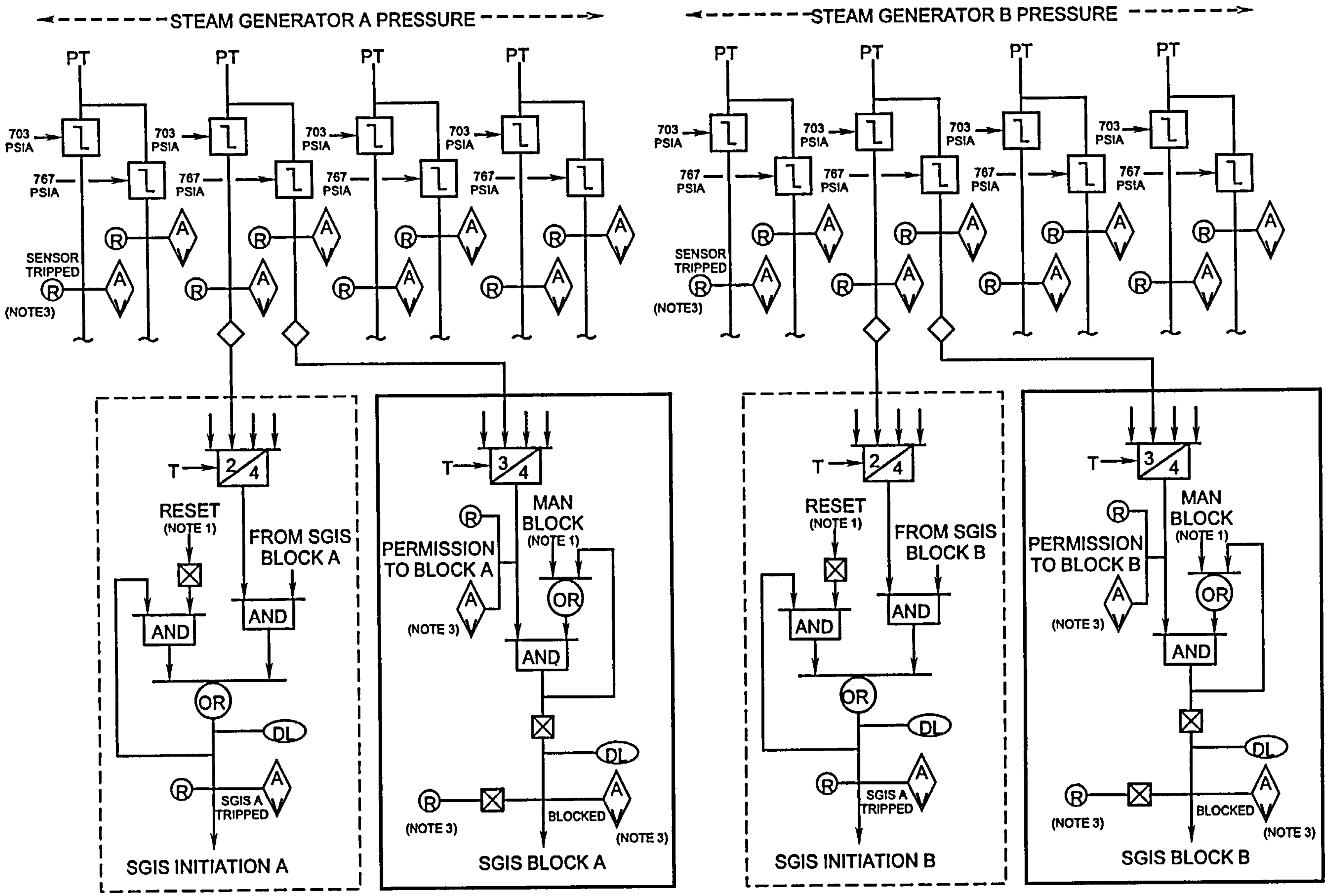


Figure 10.3-5 Recirculation Actuation Signal Logic

1000-1



T TEST

PT PRESSURE TRANSMITTER

R LOCAL RED INDICATING ALARM LIGHT

DL OUTPUT TO PLANT COMPUTER

A REMOTE AUDIBLE VISUAL ALARM

◇ ISOLATION

NOTE 1 THIS SIGNAL IS INITIATED BY A KEYSWITCH (ONE PER CHANNEL) ON CONTROL ROOM PANEL 1C03

NOTE 2 THIS SIGNAL IS INITIATED BY LOCAL PUSHBUTTONS(ONE PER CHANNEL) ON THE ASSOCIATED LOGIC ACTUATION CABINET.

NOTE 3 ALL REMOTE ALARMS ARE LOCATED ON CONTROL ROOM PANEL 1C08.

Figure 10.3-6 Steam Generator Isolation Signal Logic

1000-

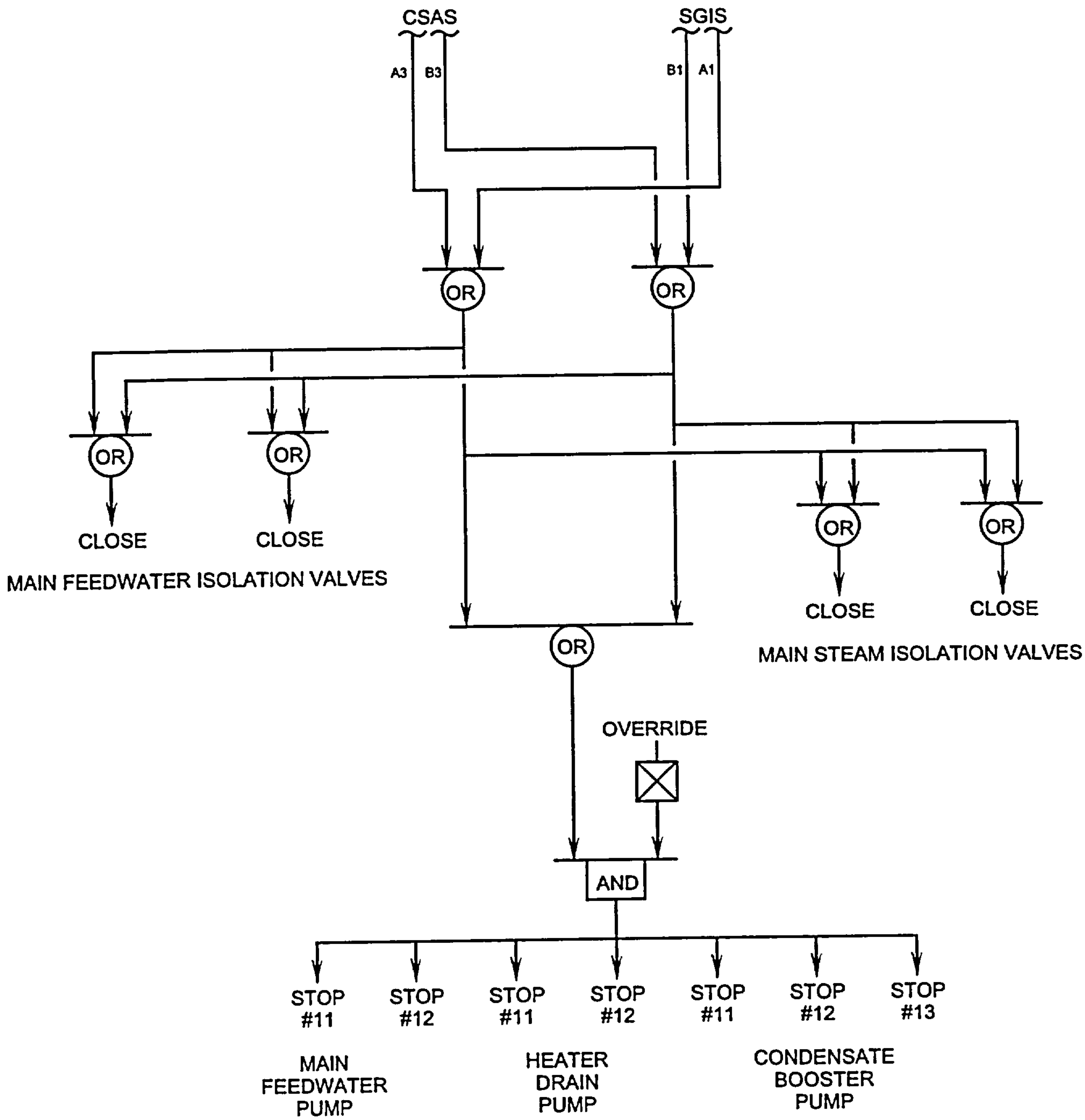


Figure 10.3-7 Steam Generator Isolation Actuation: Main Steam and Feedwater

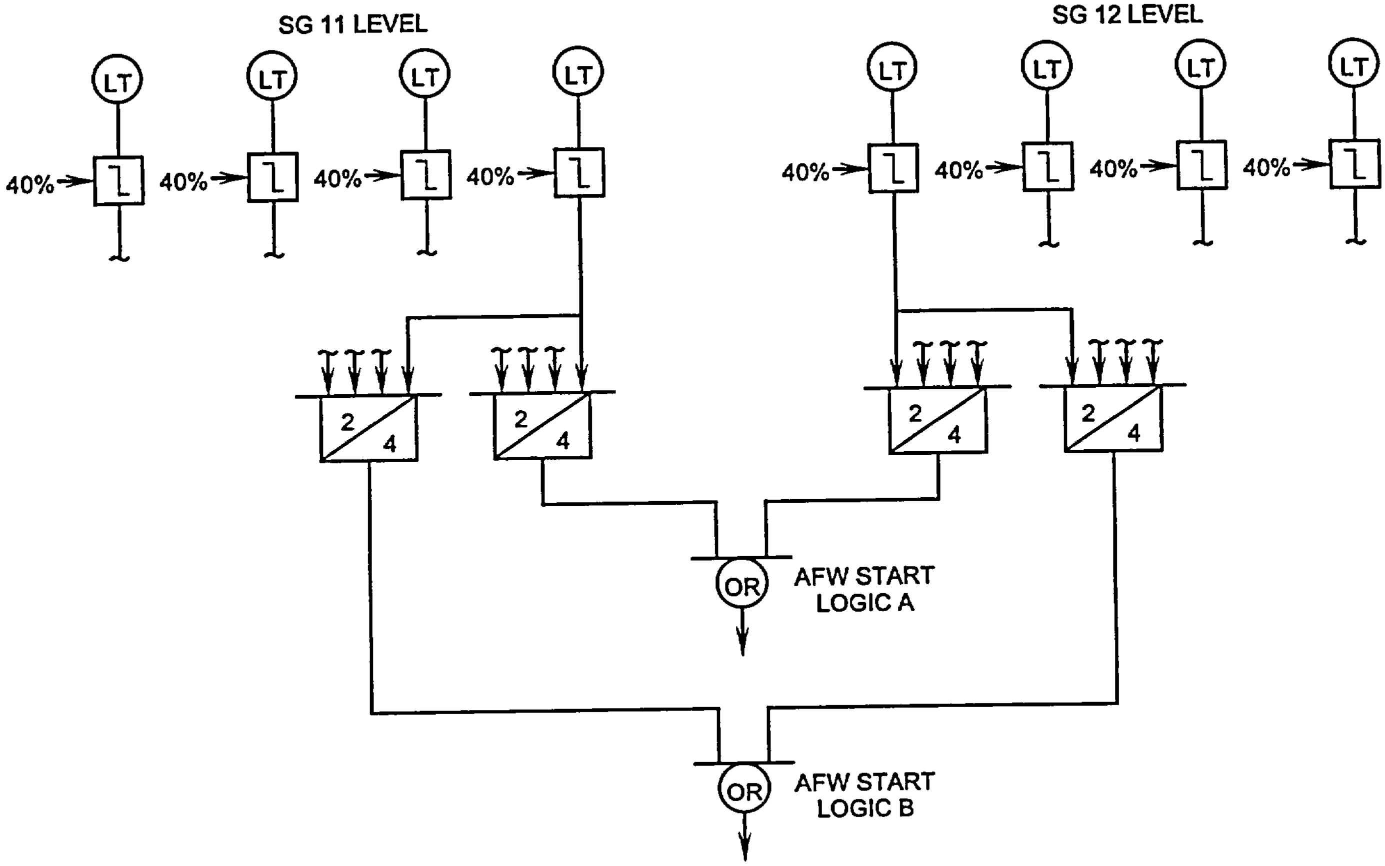


Figure 10.3-8 AFW Actuation Signal Logic

Combustion Engineering Technology
Cross Training Course Manual

Chapter 11

ENGINEERED SAFETY FEATURES

Section

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11.1 HIGH PRESSURE SAFETY INJECTION

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11.1 HIGH PRESSURE SAFETY INJECTION

Learning Objectives:

1. State the purpose of the high pressure safety injection (HPSI) system during the following plant conditions.

    a. Normal operations
    b. Injection phase following an accident
    c. Recirculation phase following an accident

2. State the purpose of the following major components:

    a. Refueling water tank (RWT)
    b. Recirculation sump

3. List the start signals for the high pressure safety injection system.

4. State the system realignments that occur when a recirculation actuation signal (RAS) is received.

11.1.1 Introduction

The purpose of the HPSI system is to inject borated water into the reactor coolant system (RCS) in the event of a loss of coolant accident (LOCA). If the break is small and the depressurization of the RCS is slow, the HPSI system is designed to provide sufficient flow to meet the ECCS design criteria as stated in 10 CFR Part 50.46. The HPSI system will also be used during the recirculation mode of operation to cool the core by supplying water to the core and matching decay heat boil off.

11.1.2 System Description

The HPSI system is aligned for operation as shown in Figure 11.1-1. The HPSI pumps are normally aligned to take a suction from the refueling water tank (RWT) or, during the recirculation mode of operation, from the containment recirculation sump

Upon actuation, the pumps start and the high pressure isolation valves open. The HPSI pumps discharge into the RCS, if the pressure in the RCS is below the shutoff head of the HPSI pumps. In the event that the pumps are started and the RCS pressure is greater than the shutoff head of the HPSI pumps, a minimum flow is recirculated back to the RWT via recirculation valves. This minimum flowpath provides pump protection. The system is designed with two (2) redundant pumps and flow paths so that either train will perform the function of cooling the core in the event of a LOCA.

11.1.3 Component Description

11.1.3.1 Refueling Water Tank

The RWT is constructed to meet the requirements of a seismic category I structure or component and is normally used to fill the refueling canal and transfer tube for refueling operations. Figure 11.1-2 shows the normal piping and instrumentation associated with the RWT.

The RWT is sized to contain approximately 420,000 gallons of water of which about 400,000 gallons are required for the availability of the safety injection and containment spray systems. The RWT is vented to the atmosphere through the overflow line. The vent line is sized for tank integrity during all thermal and pumping transients.

The volume of water required by the safety injection and containment spray systems is approximately 400,000 gallons. This provides sufficient water so that the engineered safety features pumps can take a suction from the RWT for a minimum of 36 minutes after initiation of the emergency core cooling systems and provides adequate water for long-term recirculation. This sizing requirement is based upon all the following pumps operating and injecting into the RCS or the containment: three (3) high pressure safety injection pumps, two (2) low pressure safety injection pumps, and two (2) containment spray pumps.

The water in the RWT is maintained at a boron concentration between 2300 and 2700 ppm. Since the RWT contains boric acid, there is a minimum temperature specification of 40°F to prevent boron precipitation. Proper boron concentration in the RWT is maintained by the chemical and volume control system (CVCS). A connection from the RWT to the CVCS is provided to supply RWT water to the suction of the charging pumps when the volume control tank (VCT) reaches a low-low level set point. This connection can also be used to allow borated make-up water to be supplied to the RWT from the CVCS.

The RWT has two outlet lines which supply borated water to the HPSI pumps, LPSI pumps, and containment spray pumps. These two outlet lines are physically separated to minimize the possibility of simultaneous plugging. Each outlet has a protective screen such that any particle size passed can also be passed by all components in the systems using this water. In addition, each RWT outlet line has a motor operated isolation valve which is controlled by hand switches located in the control room. Each hand switch has an open and shut position indication, in addition to a shut position annunciator.

The RWT has instrumentation which provides indication of RWT level and temperature. RWT level provides inputs to the engineered safety features actuation system (ESFAS) for the recirculation actuation signal (RAS). When two (2) of the four (4) level switches sense a low level (30 inches) in the RWT, a RAS is generated by the ESFAS. RWT temperature indication is provided by two redundant temperature elements. Each temperature channel provides a high/low (95°F / 55°F) alarm signal.

A refueling water heat exchanger and circulating pump are used to maintain the RWT contents above the minimum temperature. The plant heating system supplies hot water to the refueling water heat exchanger which will provide the necessary heat source for the RWT. The circulating pump takes a suction on the RWT and discharges RWT water through the heat exchanger and back to the RWT.

The RWT has a drain line and an overflow line which combine and send RWT water to the miscellaneous waste receiver tank. Two other lines allow the RWT contents to be transferred to and from the spent fuel pool and the refueling pool via the spent fuel pool cooling and purification system. Additional technical data for the RWT is presented in Table 11.1-1.

11.1.3.2 High Pressure Safety Injection Pumps

The HPSI pumps are located in the auxiliary building. Each pump is a 100 percent capacity pump. One pump and its associated four (4) high pressure injection valves receives power from one (1) of the two (2) emergency diesel generators, the other pump and its associated injection valves receives power from the other diesel generator. This ensures the automatic operation of one (1) full capacity train in the unlikely event of simultaneous accident, loss of offsite power, and the failure of an emergency diesel generator to start.

The HPSI pumps can be started or stopped from the control room as long as a safety injection actuation signal (SIAS) is not present. The starting of the pumps by a SIAS signal is governed by the availability of the offsite power sources.

If offsite power is available (normal power supply breaker to the ESF bus closed), the pumps will start immediately. If offsite power is not available, the HPSI pumps will start 25 seconds (time delay) after the diesel generator output breaker closes and supplies power to the ESF bus. The last possible situation is to have offsite power at the beginning of the accident and to lose the power source some period of time later.

Upon receipt of a SIAS, HPSI pumps 11 and 13 would start from their respective offsite power source. The loss of offsite power would actuate the load shed circuitry, and the pumps would stop. When the diesel generator starts to supply power to the ESF bus, the load shed signal is cleared, and the pumps will then restart after satisfying a time delay.

HPSI pump 13 was originally intended as an installed spare and was normally aligned as an "A" train pump. This pump can receive power from either the "A" or "B" train vital power. Its power supply is selected to the train to which the pump is aligned. Cross connecting power from two different trains is prevented by a key interlock breaker arrangement for this pump. This pump also received an automatic start signal from either SIAS train. The SIAS start signal to the 13 HPSI pump was controlled by the power supply source and the status of the other HPSI pump that shares the ESF bus.

The present alignment is with HPSI pump 11 powered from the 11 4kV vital bus and HPSI pump 13 selected to the 14 4kV vital bus. Both pumps receive a start signal on an SIAS. The 12 HPSI pump does not receive a start signal on an SIAS. This alignment does not provide for a "swing" pump capability.

Each HPSI pump is a multiple stage centrifugal pump. The pumps are provided with a mechanical seal at each end of the shaft. The seals are designed for operation with temperature in excess of 300°F, but are cooled to increase seal life and reduce maintenance. Seal cooling is accomplished by circulating a portion of the water from the first stage through a centrifugal separator and a cooler, then flushing the cooled water into the seal cavity. Leak off connections, both vent and drain, are provided between the mechanical seal and the backup shaft packing which is part of the seal cartridge. In addition to the vent and drains associated with the seal cartridge, dual casing vents and drains are installed on each pump to permit flushing to reduce radiation levels during maintenance operations.

The stuffing box jackets and two bearing housings on each HPSI pump are directly cooled by component cooling water (CCW). In addition, the CCW flows through the pump cooler to transfer heat from the seal cooling water described above.

The HPSI pumps each have a design capacity of 345 gpm and a maximum flow capability of 640 gpm with a minimum allowable flow of 30 gpm. Each pump is driven through a coupling by a 400 hp, 4000 Vac induction motor. The motor is capable of accelerating the pump to full speed in 8 seconds with 75% of the name plate voltage applied. HPSI pump 11 receives class 1E power from 4.16 kV unit bus 11 and pump 12 receives class 1E power from 4.16 kV unit bus 14. HPSI pump 13 can receive power from either bus 11 or bus 14 (normally lined up to bus 14) through the use of disconnect switches controlled by key operated handswitches. Redundant power sources provide maximum reliability for pump operation.

Each pump hand switch has four (4) positions (stop / auto / start / pull-to-lock). The start and stop positions allow manual control of the pumps, while the auto position aligns the pump for automatic operation. The pull-to-lock (PTL) position removes the pump from service by preventing pump start signals from being processed.

The number 11 and 13 HPSI pumps will start automatically upon receipt of a SIAS (in AUTO). An improper breaker lineup alarm actuates when a pump has its breakers and disconnects in any combination other than a breaker racked in with its associated disconnect shut. Each HPSI pump has a SIAS blocked auto start alarm which actuates when one of the following conditions exists:

1. Pump hand switch in PTL
2. Pump breaker racked out
3. Pump breaker not shut within one (1) second after receiving a SIAS or hand switch start signal

The HPSI pumps will be used not only during the injection phase of the LOCA but also during the recirculation mode. The HPSI pumps are sized to ensure at the start of the recirculation mode one (1) HPSI pump alone has sufficient capacity to keep the core covered, assuming 25% flow spillage, and match the boil off from core decay heat. If recirculation is initiated 36 minutes after a LOCA, the safety injection flow required to match core boil off is approximately 410 gpm. One HPSI pump with 25% spillage injects 450 gpm into the RCS when RCS pressure is at its maximum containment pressure. Thus flow from one HPSI pump is sufficient to prevent core damage at this time. Additional HPSI data is presented in Table 11.1-2.

11.1.3.3 Minimum Flow Recirculation Valves

The HPSI pumps are provided with minimum flow protection to prevent damage to the pumps which could result from operation against a closed discharge. The HPSI pumps are designed to operate with a minimum recirculation flow rate of 30 gpm without suffering damage. The pumps are also protected from run-out damage by system valve adjustments and/or orifice sizing downstream of the pumps.

The minimum flow recirculation valves are normally open and will automatically close upon receipt of a RAS. These valves close to prevent the recirculation of potentially radioactive material from the containment sump to the RWT which is outside the containment.

11.1.3.4 High Pressure Isolation Valves

There are four (4) high pressure isolation valves on each train of the high pressure injection system. Train "A" isolation valves, on the discharge of the 11 HPSI pump, receives vital power from the Train "A" vital electrical distribution network, and the valves on Train "B", on the discharge of the 13 HPSI pump, receive their power from Train "B" vital electrical distribution. These valves are normally closed and receive an open signal from the SIAS. All the high pressure isolation valves have locking control switches and position indicators in the control room, which allows the operator to change the position of these valves if needed.

11.1.3.5 Safety Injection Actuation Signal (SIAS)

The SIAS is used to automatically actuate the HPSI system. The SIAS is actuated by either of the following signals:

1. Low pressurizer pressure, or
2. High containment pressure

The low pressurizer pressure SIAS is a two (2) out of four (4) signal set at 1740 psia at normal plant operating conditions. When pressurizer pressure decreases to 1785 psia the operator may manually block the low pressure SIAS. When plant pressure is being increased and pressurizer pressure exceeds 1785 psig the set point will automatically be reinstated.

The high containment pressure SIAS is a two (2) out of four (4) signal and is set at 2.8 psig. In addition to starting the safety injection systems, this signal also generates a containment isolation and starts the containment cooling systems.

11.1.3.6 Recirculation Actuation Signal (RAS)

The RAS is used to automatically change the safety injection systems from the injection mode of operation to the recirculation mode of operation. When the RWT reaches a low level (30 inches), the RAS will be generated. This signal is a two (2) out of four (4) logic and once received will automatically stop the LPSI pumps and transfer the suction of the HPSI pumps from the RWT to the containment sump. This signal will also close the minimum flow recirculation valves.

11.1.4 System Operation

11.1.4.1 Normal Operation

During normal plant operation, the HPSI system is maintained in a standby mode with all of its components lined up for emergency injection (Figure 11.1-1). During this time none of the system components are operating. This system does provide the means to adjust the level in the safety injection tanks (SITs).

11.1.4.2 Injection Phase

If a leak in the RCS is small enough so that one charging pump can maintain reactor coolant pressure, an SIAS is not generated and the use of the safety injection systems is not required. However, if the break is large enough to cause the pressure in the RCS to decrease below 1740 psia, then an SIAS is initiated. Large ruptures up to and including the double-ended rupture of the largest pipe in the RCS are dealt with by the high and low pressure safety injection pumps and the safety injection tanks.

If standby power (offsite power) is not available following a SIAS the plant emergency diesel generators will automatically start and all loads on the engineered safety features buses will be tripped. Once the diesel generator is up to speed and voltage, its corresponding output breaker is closed and the loads will be sequenced onto the bus. The loads are sequenced on in a prescribed order to prevent overloading the diesel generators. The loading sequence is as follows:

1. Two (2) low pressure injection valves and four (4) high pressure injection valves open,

2. One (1) high pressure safety injection pump is started and

3. A low pressure safety injection pump is started.

Two (2) separate suction headers supply the three HPSI pumps with water from the RWT through two suction lines each having a motor-operated isolation valve. These valves are normally open to line up RWT water to the HPSI pumps for the injection mode of operation. Once the recirculation mode begins, the two RWT isolation valves must be shut by the operator.

HPSI pumps 11 and 12 are lined up to take a suction on one RWT header, while pump 13 is lined up to take suction on the other RWT header. The three (3) HPSI pumps discharge through check valves to a common discharge header. In this discharge header there are two (2) motor-operated isolation valves controlled by key operated hand switches. As indicated on Figure 11.1-1, MOV-653 is normally shut and MOV-655 is normally open. Control of these valves allow realignment during normal operations or in the event of a casualty to the main or auxiliary discharge headers.

Each HPSI header has a motor-operated isolation valve (MOV-654 and MOV-656) which are controlled by key operated hand switches. Both valves receive an open signal when a SIAS is generated by the ESFAS.

Downstream of each header isolation valve is a pressure transmitter to provide pressure indication to the operator. A system relief valve in each header provides over pressure protection due to a possible sudden increase in temperature. After the relief valve, the auxiliary header has a connection to the discharge of the charging pumps in the CVCS. This connection provides an alternate charging path to the RCS.

After the header relief valve, each header (main and auxiliary) splits into four (4) parallel lines. Each HPSI line has a motor-operated isolation valve controlled by a hand switch. All the isolation valves are normally shut, and open automatically upon receipt of a SIAS. The valves can be positioned to throttle HPSI flow. A percent valve position indicator is provided next to each hand switch. Each of the main HPSI lines then joins a respective auxiliary HPSI line forming a common HPSI line. The common HPSI lines passes through a check valve and a flow element prior to combining with a respective LPSI line and SIT to form one (1) of four (4) injection paths into the RCS.

The safety injection systems will inject water into the RCS via the penetrations on the four (4) cold legs. The size of the break will determine how long the water in the refueling water tank will last. For the large break LOCA , the level will decrease to the low level alarm set point at which time the RAS will automatically shift the safety injection systems from the injection phase to the recirculation phase.

11.1.4.3 Recirculation Phase

When the water in the RWT reaches a low level (6 percent) the RAS is initiated. The RAS opens the containment sump isolation valves, stops the low pressure safety injection pumps, and closes the minimum flow recirculation valves. The HPSI pumps continue to operate during this switch over. The safety injection systems are now aligned for the recirculation phase. Once initiated, recirculation continues until terminated or modified by operator action.

A recirculation line is provided from the outlet of each shutdown cooling heat exchanger to the HPSI pump suction. Heat exchanger 11 connects to HPSI pump 11 and 12 and heat exchanger 12 connects to HPSI 13. Each recirculation line has a motor-operated isolation valve controlled by a hand switch. These two (2) isolation valves are normally shut. They are opened by the operator if HPSI pump cavitation occurs during the recirculation mode of operation. Recirculation of the cooler containment spray water from the heat exchanger outlet maintains the HPSI pump's suction sufficiently subcooled to prevent cavitation.

During long term core cooling following a LOCA, if the reactor coolant is not sub-cooled it will boil off as steam. The boiling process concentrates the boric acid and other solution additives in the core. For a hot leg break, safety injection flow via the cold leg travels down the annulus , through the core, and out the break. A flushing path is established through the reactor vessel, precluding the build-up of solids in the core region.

However, for a cold leg break, only that amount of injected water required for decay heat removal is delivered to the core; the remainder spills out the break. Due to the RCS geometry, there is minimal flushing flow through the core for a cold leg break, and boric acid concentration may increase along the core surfaces.

To prevent the restriction of core flow due to boron crystallization, the safety injection system is lined up during long term core cooling to establish a circulation flow path which adequately flushes the core.

Two safety injection lineups can be used to establish a core flush. The preferred lineup is called pressurizer injection. The four (4) auxiliary HPSI line isolation valves are shut and the HPSI pump discharge is directed to the CVCS through the cross-connect from the HPSI auxiliary header. The charging loop isolation valves are closed, then the auxiliary spray valve is opened. Flow is from the auxiliary header to the CVCS and into the pressurizer through the auxiliary spray line, and then into the core via the hot leg.

11.1.5 Summary

The HPSI system is designed to supply water from the RWT to the RCS to provide core cooling for all size breaks up to and including the double ended rupture of the largest piping in the RCS. Redundancy is built into the HPSI system by incorporating three (3) 100 percent capacity pumps and two (2) separate trains of injection. During long term cooling of the core (recirculation mode), heat is removed by returning water from the containment sump via the HPSI system to the core, and allowing the core to boil off this liquid.

TABLE 11.1-1
REFUELING WATER TANK

Quantity	1 per unit
Type	Vertical cylinder
Total volume	420,000 gallons
Minimum water volume	400,000 gallons
Design pressure	Atmospheric
Design temperature	0°F
Contained liquid	Borated water
Liquid temperature	Ambient (40°F to 100°F)
Material	Type 304 stainless steel
Seismic requirement	Class I

TABLE 11.1-2
HIGH PRESSURE SAFETY INJECTION PUMPS

PUMP

Quantity	3 per unit
Manufacturer	Bingham
Type	7-stage, horizontal, centrifugal
Material	Stainless steel
Design flow rate	345 gpm
Design head	2500 ft.
Maximum flow rate	640 gpm
Head at max, flow rate	1360 ft.
Minimum allowable flow rate	30 gpm
Shutoff head	2930 ft.
NPSH available, minimum	28 ft.
NPSH required for 640 gpm	20 ft.
Design temperature	350°F
Design pressure	250 psig, suction 1750 psig, discharge

MOTOR

Quantity	3 per unit
Manufacturer	General Electric Co.
Horsepower	400 hp
RPM, full load	3560 rpm
Voltage rating	4000 V, 3 phase, 60 Hz.

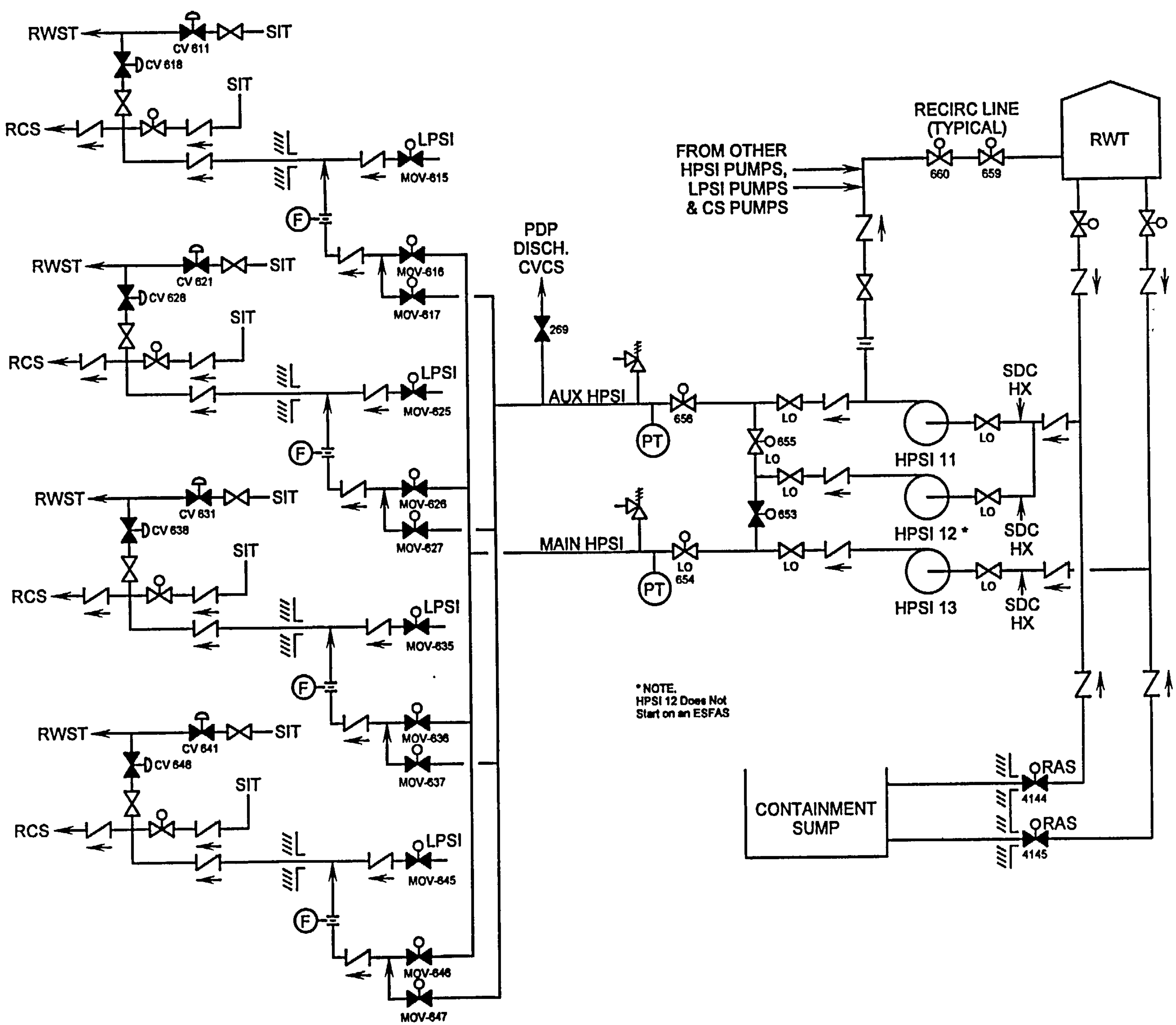

Figure 11.1-1 HPSI Flow Diagram

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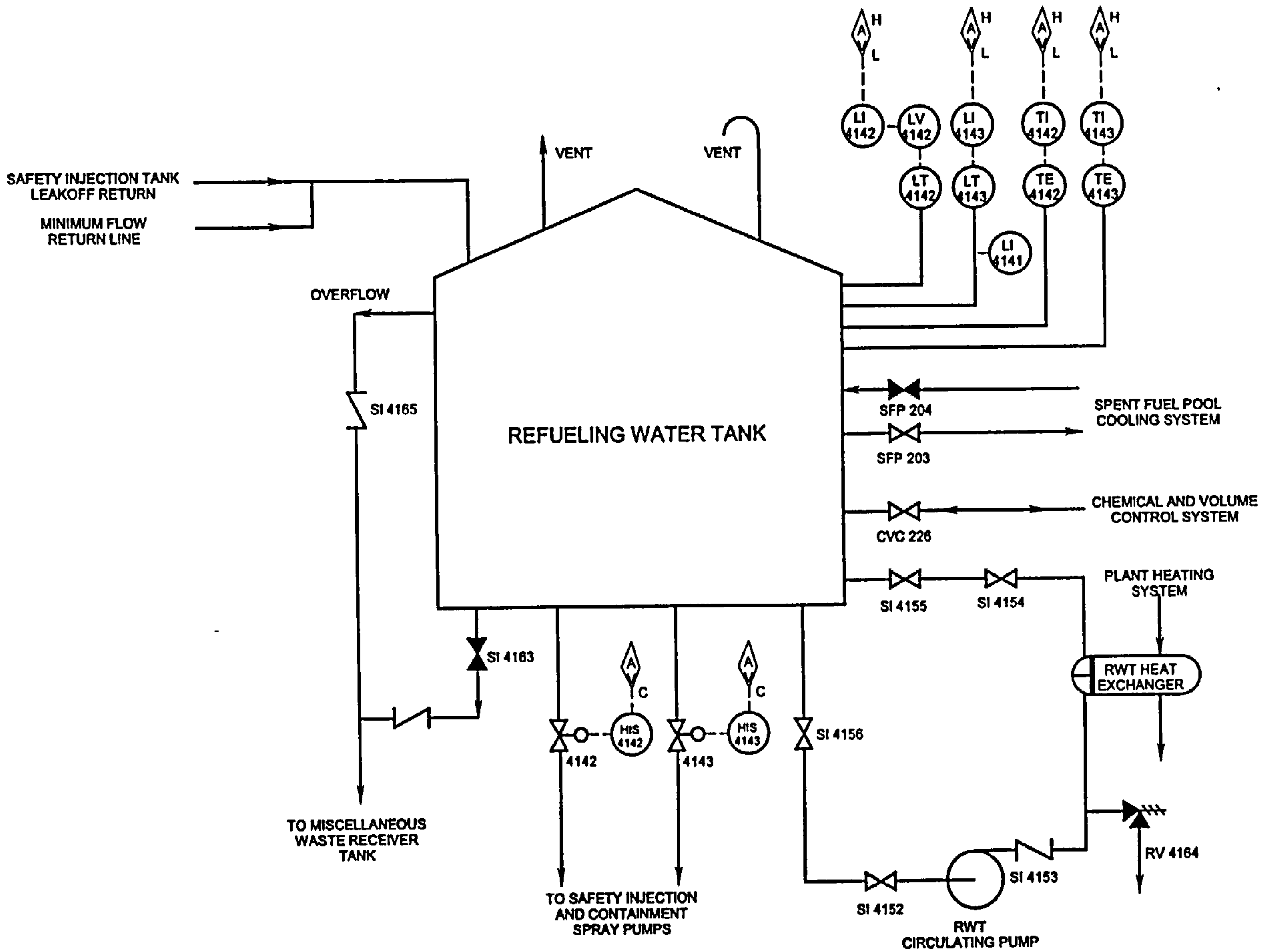

Figure 11.1-2 Refueling Water Tank

1000-11